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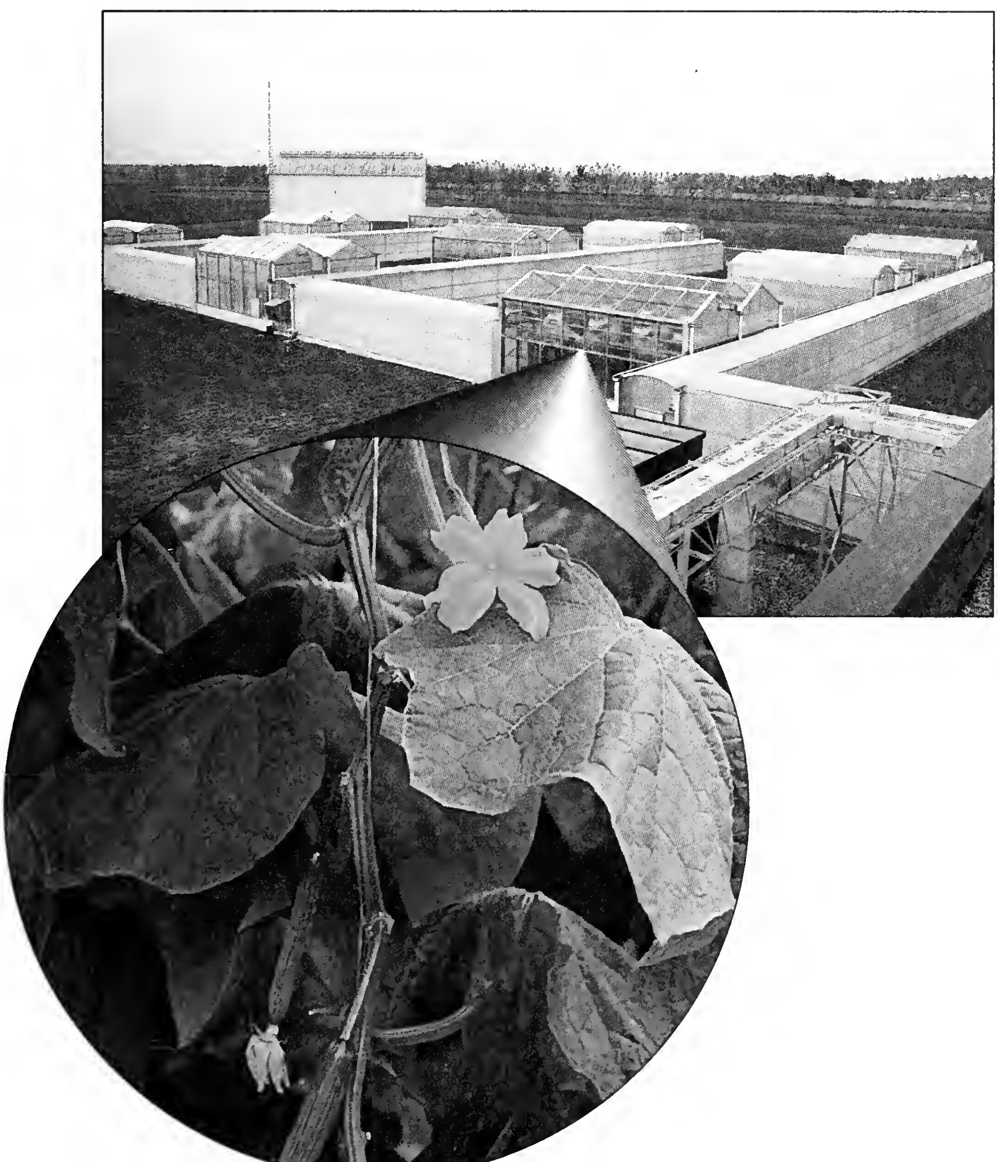
Growing greenhouse seedless cucumbers in soil and in soilless media



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Growing greenhouse seedless cucumbers in soil and in soilless media

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Cover illustration
The nine mini greenhouse research complex at the Harrow Research Station of Agriculture Canada; built in 1987 with the financial support of the Ontario Greenhouse Vegetable Producers Marketing Board and of the Department of Energy, Mines and Resources of Canada. (Photo by A.P. Papadopoulos.)

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Contents

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Introduction

Almost all cucumbers grown now in greenhouses are the long, seedless type (English or European), referred to in this booklet as seedless cucumbers. The seeded-type cucumbers (regular or American), referred to in this booklet as regular cucumbers, were popular until the mid 1970s. The regular cucumbers have disappeared from the market except for those from field production (mostly as imports). Seedless cucumbers are the second most-important greenhouse vegetable crop in Canada not far behind tomatoes. Cucumbers are grown mainly in spring and fall, but the plants' fast growth and the short time required from seeding to harvest provide great flexibility in crop planning.

The spring crop has always been the most important because of both the high prices in winter and early spring and the long season of production. This crop is normally seeded in December, set in the greenhouse the 1st week of January, and harvested from mid February to July; some plantings extended into the fall. When circumstances allow (e.g., artificial lighting for transplant raising, modern greenhouse, skilled operator), the spring crop is started even earlier to capture the lucrative winter market. However, poor light conditions during the winter months make the early spring crop more difficult to grow. The spring crop is also a riskier business venture, because of the high production inputs (i.e., energy and labor costs). For the grower choosing between cucumbers and tomatoes, the decision to grow spring cucumbers is a tough one, because this crop must compete with the equally important spring crop of tomatoes.

The choice in the fall is easier, because the season is much shorter, the anticipated yield correspondingly low, and the prices are usually depressed until late in the season. Their quick growth in relation to the time available makes cucumbers a good candidate for a fall crop. Such a crop is normally seeded in July, set in the greenhouse during the 1st week of August, and harvested from September to December.

The recent rise of sweet peppers as a serious contender makes choosing between cucumbers and tomatoes as a greenhouse crop even more difficult.

The cucumber plant

Origin

The cucumber most likely originated in India (south foot of the Himalayas), or possibly Burma, where the plant is extremely variable both vegetatively and in fruit characters. It has been in cultivation for at least 3000 years. From India the plant spread quickly to China, and it was reportedly much appreciated by the ancient Greeks and Romans.

Botanical taxonomy

The cucumber (*Cucumis sativus* L.) belongs to the Cucurbitaceae family, one of the more important plant families. The Cucurbitaceae consists of 90 genera and 750 species.

The Cucurbitaceae family is divided into five subfamilies (i.e., Fevilleae, Melothriae, Cucurbiteae, Sicyoideae, and Cyclanthereae). However, the important cultivated genera are found only in the subfamilies Cucurbiteae (i.e., *Citrullus*, *Cucumis*, *Luffa*, *Lagenaria*, and *Cucurbita*) and Sicyoideae (i.e., *Sechium*).

The genus *Cucumis* contains nearly 40 species including three important cultivated ones (i.e., *C. anguria* L. [West Indian gherkin], *C. sativus* [cucumber], and *C. melo* L. [cantaloupe]).

Other important crop plants in the Cucurbitaceae family are watermelon (*Citrullus vulgaris* Schrad), muskmelon (*Cucumis melo* L.), squash and pumpkin (*Cucurbita pepo* L., *C. mixta* Pang., *C. moschata* Poir., and *C. maxima* Duch.), and loofah gourd (*Luffa cylindrica* Roem.).

Fig-leaf gourd (*Cucurbita ficifolia* Bouché) is also cultivated to some extent, but it is even more important as a disease-resistant rootstock in the grafting of greenhouse cucumbers.

Plant growth habit

The cucumber responds like a semitropical plant. It grows best under conditions of high temperature, humidity, and light intensity and with an uninterrupted supply of water and nutrients.

Under favorable and stable environmental and nutritional conditions and when pests are under control, the plants grow rapidly and produce heavily. The main stem, laterals, and tendrils grow fast. They need frequent pruning to a single stem and training along vertical wires to maintain an optimal canopy that intercepts maximum light and allows sufficient air movement. Under optimal conditions, more fruit may initially develop from the axil of each leaf than can later be supported to full size, so fruit may need thinning. Plants allowed to bear too much fruit become exhausted, abort fruit, and fluctuate widely in productivity over time. Rapid growth, thick and brittle stems, large leaves, long tendrils, deep green foliage, profusion of fruit, and large, deep yellow flowers indicate excessive plant vigor.

On the other hand, cucumbers are very sensitive to unfavorable conditions, and the slightest stress affects their growth and productivity. Because fruit develops only in newly produced leaf axils, major pruning may be needed to stimulate growth; the removal of entire weakened laterals is more effective than snipping back their tips.

The shoot

The main stem of this herbaceous and annual plant begins growing erect but soon after assumes a prostrate trailing habit and grows like a vine over the ground. The branching is of the sympodial type (i.e., a lateral bud at each node grows and displaces the main growing point, the latter assuming a position on the opposite side of the leaf). From the nodes of the main axis originate primary laterals, each of which can have their (secondary) laterals, and so on. All stems are roughly hairy, have an angular cross section, may turn hollow when mature, and bear leaves singly at the nodes.

The large, simple leaves (10–20 cm in the regular cucumber, 20–40 cm in the seedless cucumber) are each borne on long (7–20 cm) petioles. They have five angular lobes of which the central is the largest, and many trichomes cover the surface. At each node above the first three to five, a simple unbranched tendril grows from the base of the petiole. The sensitive tendrils enable the stems, which can not twist themselves, to climb over other plants or objects. A tendril tip, upon touching a support, coils around it; then the rest of the length of the tendril coils spirally, pulling the whole plant towards the support.

A cross section of the stem reveals 10 vascular bundles arranged in two rings. The smaller vascular bundles of the outer ring (first five) are located at the angles of the stem; the larger bundles (remaining five) form the inner ring.

The root

A strong tap root characterizes the root system and may reach 1 m deep. Overall the root system is extensive but rather shallow; many horizontal laterals spread widely and rapidly producing a dense network of rootlets that colonizes the top 30 cm of the soil and usually extends farther than the vine.

Some of the lateral roots eventually grow downwards producing a new system of deeper laterals, which replaces in function the tap root as the plant ages. When the base of the plant is hilled and favorable moisture conditions exist, adventitious roots arise easily from the hypocotyl as well as from the nodes along the vines.

The flower

The cucumber plant displays a variety of sex types. Before describing the most common forms of the greenhouse cucumber, the following terms need explanation:

Perfect, or bisexual, or hermaphroditic flower: A flower with both male (stamens) and female (pistil) organs but possibly without a calyx (green sepals) or corolla (colorful petals).

Male, or staminate, flower: A flower lacking a pistil.

Female, or pistilate, flower: A flower lacking stamens.

Monoecious plant: A plant bearing both male and female flowers.

Dioecious plant: A plant species bearing male flowers on one plant and female flowers on a different plant.

Androecious plant: A plant carrying only male flowers.

Andromonoecious plant: A plant carrying some perfect and some male flowers.

Gynoecious plant: A plant carrying only female flowers.

Gynomonoecious plant: A plant carrying some perfect and some female flowers.

Predominantly female plant: A plant with mostly female flowers, but also carrying a few male flowers.

Hermaphroditic plant: A plant carrying both male and female flowers.

Parthenocarpy: Reproduction without fertilization; in this case, production of seedless fruit without pollination.

Normally the cucumber is a monoecious plant with male and female flowers borne on the same plant (e.g., the American-type greenhouse cucumber, or the pickling cucumber). It reproduces with a high degree of cross-pollination. Therefore, the regular cucumber and nearly all field cucumbers require pollination, which is usually assisted by bees; one colony of honey bees per 50 000 plants is recommended.

However, the greenhouse-grown English cucumber is mostly of the gynoecious or, rarely, the predominantly female type. This parthenocarpic type of cucumber needs no pollination. In fact, pollination is undesirable because it results in seed set, club-shaped fruit, and loss of revenue. To prevent cross-pollination by stray bees, place screens on the greenhouse, especially if regular cucumbers are grown close-by.

Any factor affecting growth, including environmental factors, can affect sex expression in cucumbers. Research with monoecious plants has shown that good conditions, such as high temperature (>27°C), long days (>14 h), sunny weather, high nitrogen, and ample water supply, promote male flower development. Poor conditions promote more female flowers. Predominantly female hybrids generally respond to environmental stress in the same way. However, gynoecious plants (100% female flowers) are not affected by the environment.

Spraying plants with plant-growth substances (man-made plant hormones) can also influence the sex expression of cucumbers. It is possible to initiate and maintain a female flowering habit indefinitely by spraying monoecious plants repeatedly with ethephon at prescribed rates. Ethephon sprays can also ensure continuous female flower development in predominantly female plants. It is also possible to initiate development of male flowers, even on gynoecious plants, by spraying them with gibberellic acid at the proper concentration. This technique is extremely useful in the hands of the breeder because it facilitates the self-pollination of a female parent line, which otherwise would have been impossible to maintain.

Both male and female flowers have deep yellow, five-lobed petals (Fig. 1). The male flowers, each supported by a slender peduncle (stem), are generally borne in clusters of 3–5 at leaf-nodes. Each male flower has

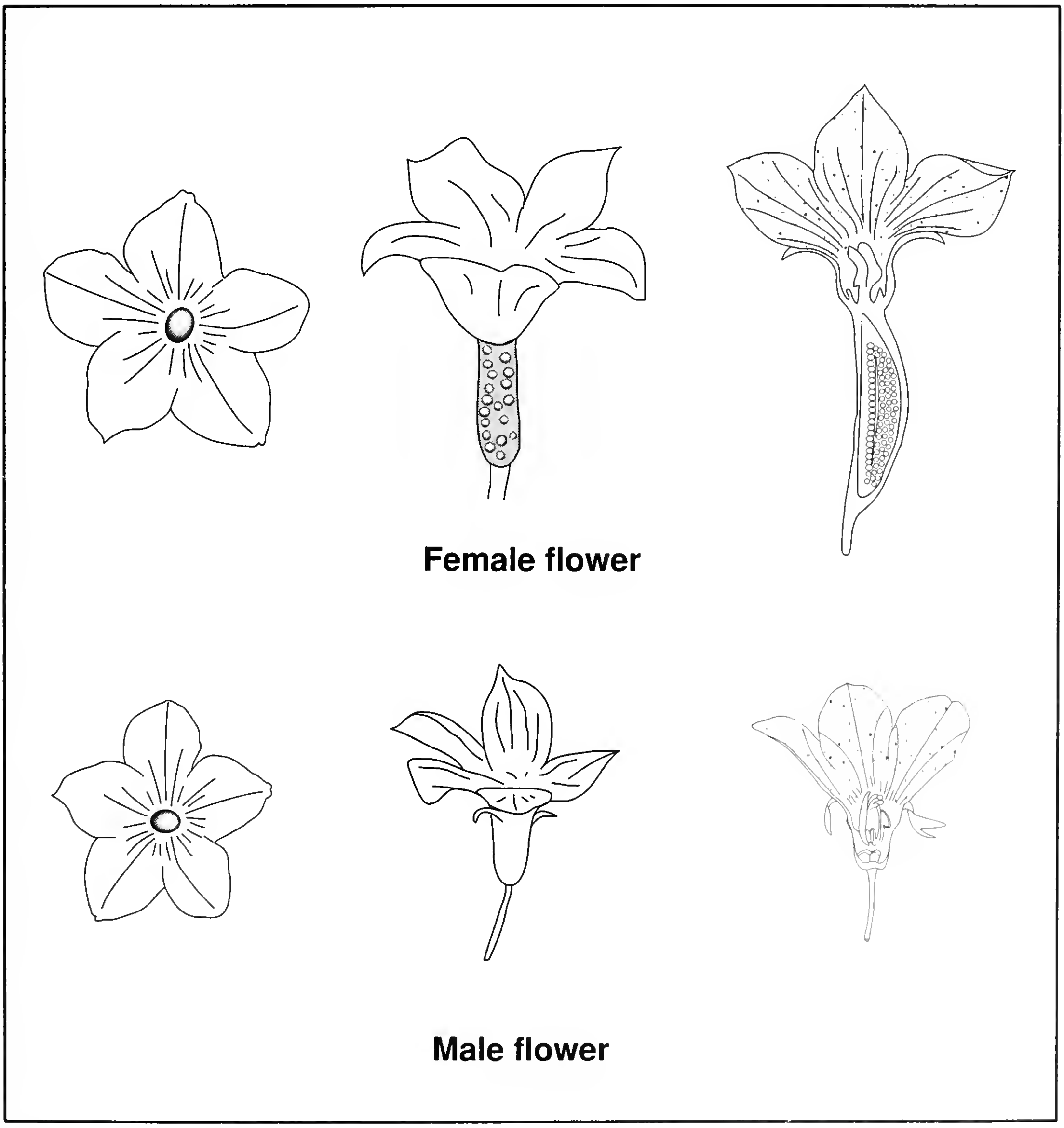

Fig. 1 Morphological and anatomical variation of the cucumber flower.

three stamens, of which two have two anthers and the other has only one anther. The female flowers are borne singly at nodes of the main stem and of side shoots. Female flowers have atrophic (small and nonfunctional) stamens but well-developed pistils (consisting of three bilobed stigmas, the style, and a three-chambered ovary). They are easily recognizable by the large ovary at the base of the flower. A ring-shaped nectary surrounds the base of the style. The fruit, being an enlarged ovary, can only develop from a female or bisexual flower.

The fruit (seeded vs nonseeded)

Botanically, the fruit is a false berry or pepo, elongated and round–triangular in shape. Its size, shape, and color vary according to the cultivar (Fig. 2). In the immature fruit, chlorophyll in the cells under the epidermis causes the rind to be green, but, upon maturity, it turns yellow-white. The epidermal layer may have proliferated (warty) areas, each bearing a trichome (spiky hair). The fruit cavity (three locules) contains soft tissue (placenta) in which the seeds are embedded.

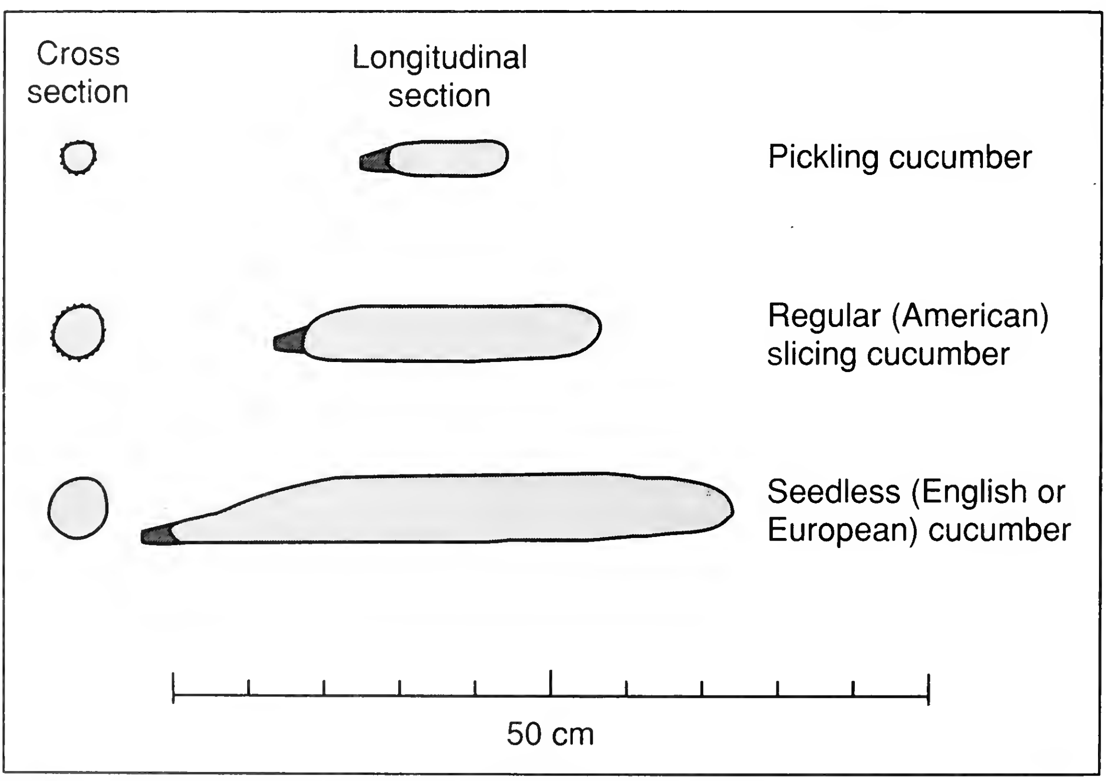

Fig. 2 Size and shape variation of the cucumber fruit.

The regular cucumber bears actual seeds (seeded cucumber), whereas the English cucumber bears either no seeds (seedless cucumber) or barely distinguishable atrophic seeds.

Regular cucumbers are short (about 15–25 cm) and uniformly cylindrical. Their thick, deep green skin has light green stripes and a rough surface with strong trichomes. The skin is bitter in taste and not easily digested, so the fruit needs to be peeled before eating.

English cucumbers are long (about 25–50 cm) and cylindrical, with a short, narrow neck at the stem end. Their rather smooth surface has slight wrinkles and ridges. The thin skin is uniformly green and not bitter, so the fruit need *not* be peeled before eating.

The cucumber fruit, like that of other Cucurbitaceae, is noted for its high water content, which is around 95% of its fresh weight. The nutritive value of 100 g of edible cucumber is as follows: energy 12 cal, protein 0.6 g, fat 0.1 g, carbohydrate 2.2 g, vitamin A 45 IU, vitamin B_1 0.03 g, vitamin B_2 0.02 g, niacin 0.3 g, vitamin C 12 g, calcium 12 mg, iron 0.3 mg, magnesium 15 mg, and phosphorus 24 mg.

Seed germination

The cucumber is a dicotyledonous plant, so its seed consists of the embryo (miniature plant) and two large cotyledons (food storage for the embryo) enclosed by the seed coat. The seed is fairly large (largest dimension about 1 cm) and flat in shape.

One gram of seed contains about 28 seeds (800 in an ounce). The seed remains viable for 4 years, but after that its germination rate falls rapidly. Using modern technology, most seed companies commonly seal seed in airtight containers filled with carbon dioxide, which preserves it for many years.

The appropriate depth of seeding is 1–2 cm. Because of the shape of the seed, it most likely lies flat at seeding. Under favorable conditions, the primary root takes 2 days to grow out of the seed coat; it then extends downward at a right angle to the seed. The root grows rapidly and may be more than 3 cm in length by the end of the 3rd day. At this time a parenchymatous outgrowth develops in the angle formed by the small horizontal part of the hypocotyl and the vertical radicle (Fig. 3).

As this outgrowth (peg) enlarges, the primary root starts to produce lateral roots, and the hypocotyl then elongates upward. The cotyledons remain in the seed coat until they are eventually freed, as the arching hypocotyl extends further, and, by their 6th day, the axis becomes straight. This type of germination is termed epigeal.

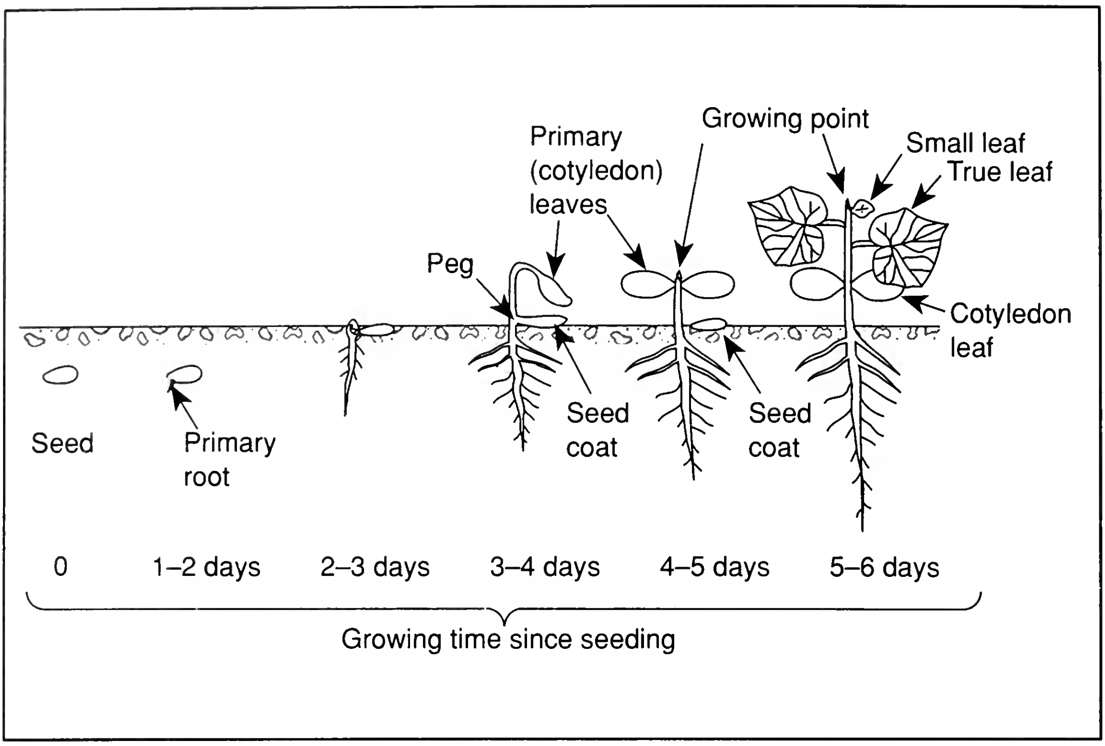

Fig. 3 Cucumber seed germination.

Plant improvement

Traditionally, the oldest and simplest way to improve crop plants was to save seed from plants that had desirable characters, e.g., high yield and good flavor. This approach leads to crop improvement only when genetic diversity exists to begin with and the plants breed true (i.e., desirable characters are transferred unaltered from generation to generation). Natural outcrossing (hybridization) occurs when a group of plants from one variety is pollinated by another distinct group of plants by wind, insects, or other natural means. However, because nature's way of creating variability is too slow, the plant breeder usually resorts to artificial ways of producing it.

Artificial hybridization involves the crossing of two or more parents chosen for carrying desirable characters. Breeders frequently use this method to generate variation from which to select useful plants. In contrast to natural hybridization, which is slow and random, artificial hybridization is controlled and more effective.

The cucumber is a cross-pollinated plant characterized by parthenocarpy (i.e., production of seedless fruits without pollination). Parthenocarpy is of economic importance in the breeding and production of cucumbers because it bypasses the laborious and costly process of artificial pollination. Hybrid vigor in cucumbers is particularly pronounced, resulting in 20–40% yield increase in relation to the parent lines. Thus for commercial production, seed companies release F1 hybrids almost universally. Furthermore, because the monoecious types are too

vigorous and need frequent pruning, nearly all new hybrids are gynoecious types selected for high yield and moderate vigor.

Within the Cucurbitaceae family, plants of the same species and, in rare instances, even plants of different species will cross pollinate. However, cucumbers will not pollinate with pumpkins, squashes, gourds, and watermelons, because they are not of the same genus. Neither will they pollinate with some melons that belong to the same genus but are of different species.

Environmental requirements

The greenhouse environment has a profound effect on crop productivity and profitability. In this section, environment includes only temperature, light, relative humidity, carbon dioxide, and air movement. Other related subjects, such as water and nutrients, are discussed elsewhere.

Temperature

Air temperature is the main environmental component influencing vegetative growth, flower initiation, fruit growth, and fruit quality (Plate I*a–i*). Growth rate of the crop depends on the average 24-h temperature—the higher the average air temperature the faster the growth. The larger the variation in day–night air temperature, the taller the plant and the smaller the leaf size. Although maximum growth occurs at a day and night temperature of about 28 °C, maximum fruit production is achieved with a night temperature of 19–20 °C and a day temperature of 20–22 °C. The recommended temperatures in Table 1 are therefore a compromise designed for sustained, high fruit productivity combined with moderate crop growth throughout the growing season.

During warm weather (i.e., late spring and early fall), reduce air temperature settings, especially during the night, by up to 2 °C to encourage vegetative growth when it is retarded by heavy fruit load. This regime saves energy because a 24-h average can be ensured by the prevailing high temperatures and favorable light conditions.

Table 1 Recommended air temperatures for cucumber cropping

	Low light (°C)	High light (°C)	With carbon dioxide (°C)
Night minimum[a]	19	20	20
Day minimum	20	21	22
Ventilation	26	26	28

[a] A minimum root temperature of 19 °C is required, but 22–23 °C is preferable.

Light

Plant growth depends on light. Plant matter is produced by the process of photosynthesis, which takes place only when light is absorbed by the chlorophyll (green pigment) in the green parts of the plant, mostly the leaves. However, do not underestimate the photosynthetic productivity of the cucumber fruit, which, because of its size and color, is a special case.

In the process of photosynthesis, the energy of light fixes atmospheric carbon dioxide and water in the plant to produce such carbohydrates as sugars and starch. Generally, the rate of photosynthesis relates to light intensity, but not proportionally. The importance of light becomes obvious in the winter, when it is in short supply. In the short, dull days of late fall, winter, and early spring, the low daily levels of radiant energy result in low levels of carbohydrate production. Not only do the poor light conditions limit photosynthetic productivity, but also the limited carbohydrates produced during the day are largely expended by the respiring plant during the long night. The low supply of carbohydrates available in the plant during the winter seriously limits productivity, as evidenced by the profusion of aborted fruit. A fully grown crop benefits from any increase in natural light intensity, provided that the plants have sufficient water, nutrients, and carbon dioxide and that air temperature is not too high.

Relative humidity

High relative humidity generally favors growth. However, reasonable growth can be achieved at medium or even low relative humidity. The crop can adjust to and withstand relative humidity from low to very high but reacts very sensitively to drastic and frequent variation in relative humidity. Its sensitivity to such variation is greatest when the crop is developed under conditions of high relative humidity. Other disadvantages of cropping under conditions of high relative humidity include the increased risk of water condensing on the plants and the development of serious diseases. The resultant low transpiration rates are blamed for inadequate absorption and transport of certain nutrients, especially calcium to the leaf margins and fruit. At low relative humidity, irrigation becomes critical, because large quantities of water must be added to the growth medium without constantly flooding the roots and depriving them of oxygen. Furthermore, low relative humidity favors the growth of powdery mildew and spider mites, which alone can justify installing and operating misting devices.

Note that relative humidity (RH) is an expression of the actual water vapor pressure (e) expressed as a percentage of the maximum water vapor pressure possible (es) under certain air temperature and atmospheric pressure conditions. Therefore, RH comparisons are not meaningful when air temperature is also changed. A more reliable indicator of the drying power of the atmosphere is the water vapor pressure deficit (i.e., VPD = es – e). A high VPD indicates a "dry" atmosphere whereas a low

VPD indicates a "wet" atmosphere. As more environmental computers become available enabling growers to measure (and become familiar with the concept of) VPD, reference to RH should be avoided.

Carbon dioxide

In cold weather, with no ventilation, have a minimum carbon dioxide concentration of 1000 vpm ($\simeq$1000 ppm) during the day. In the summer, with ventilation, supplemental carbon dioxide applied at a concentration up to 400 ppm has proved economically useful in some countries. However, this technique is too new in Canada to support definite recommendation. Regions with a moderate maritime climate, such as British Columbia, can more likely benefit from carbon dioxide applied in the summer. But in regions with a continental climate, such as southwestern Ontario, the need to ventilate the greenhouse actively throughout the hot summer renders the practice less economical.

Air movement

An approximate air speed of 0.5 m s^{-1}, which causes leaves to move slightly, is recommended. Horizontal air movement helps in several ways. It minimizes air temperature gradients in the greenhouse and removes moisture from the lower part of the greenhouse (under the foliage). It distributes moisture in the rest of the greenhouse and helps the carbon dioxide from the top of the greenhouse to travel into the leaf canopy, where it is taken up and fixed in photosynthesis. Even modest air movement in the greenhouse improves the uniformity of the greenhouse environment, which generally benefits crop productivity and energy conservation.

Nutritional needs

Soil–plant relationships

Plants in their natural environment live, almost without exception, in an association known as the soil–plant relationship. Soil provides for the four basic needs of plants: water, nutrients, oxygen, and support. Advances in science and technology now allow humans to provide these needs artificially and to successfully grow plants without soil.

The various methods and techniques developed for growing plants without soil are collectively called soilless methods of plant culture. These methods include diverse systems, from the purely hydroponic, based on water and nutrients only (e.g., nutrient film technique or NFT), to those based on artificial mixes that contain various proportions of soil. Between these extremes lie a great number of soilless methods that make use of

some sort of growing medium, either inert (e.g., rock-wool slabs, polyurethane chunks, and perlite) or not inert (e.g., gravel culture, sand culture, and peat bags).

Soil as a growth medium

Soil consists of mineral and organic matter, water, and air. An average soil in optimum condition for plant growth might consist of 45% mineral matter, 5% organic matter, 25% water, and 25% air space. The mineral matter consists of diverse small rock fragments. The organic matter of a soil is a mixture derived from plant and animal remains at various stages of decomposition. In the process of decomposition, some of the organic entities oxidize to their end-products and others to an intermediate product called humus. Both the type and the relative quantity of the mineral and organic constituents of a soil determine its chemical properties. Chemical properties of a soil are the amounts of the various essential elements present and their forms of combination, as well as the degree of acidity or alkalinity, known as pH.[1] The amount of nutrients available to the plants depends not only on the soil's chemical properties but also on its physical properties.

Soil structure and texture

The physical properties of a soil describe its texture and structure. Texture, i.e., the size distribution of its mineral constituents, is expressed as a percentage of content of sand, silt, and clay (Fig. 4). Structure describes the type and extent of formation of the various mineral and organic constituents into crumblike soil aggregates. The organic matter of a soil plays an important role in soil structure for two reasons. First, diversity in the size of the organic components produces wide variety in soil structure. Second, the humus cements together the various soil constituents into crumblike aggregates.

Soil structure in turn plays an important role in soil fertility (the ability of soil to sustain good plant growth and high yields). The structure determines, to a great extent, the water-holding capacity and aeration of a soil (Table 2).

The water held within the soil pores, together with the salts dissolved in it, make up the soil solution that is so important as a medium for supplying nutrients and water to growing plants. The air located in the soil pores supplies oxygen for the respiration of root and soil microorganisms and removes the carbon dioxide and other gases

[1] A pH of 7 indicates neutral conditions; values lower than 7 indicate an acid environment; and values higher than 7 indicate an alkaline environment on a scale of 0–14.

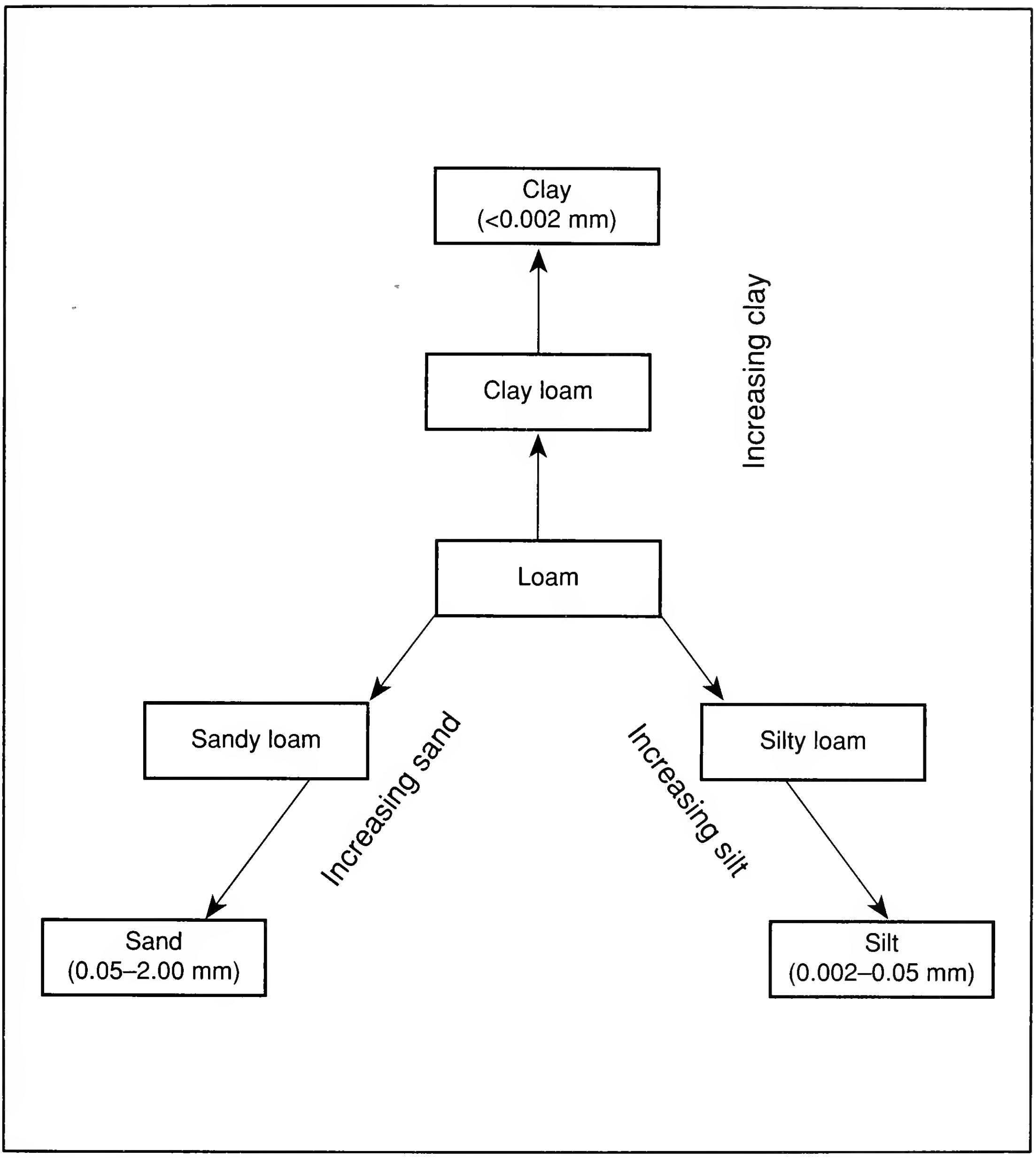

Fig. 4 Classification of soils according to texture (particle size in mm).

produced by them. Plant nutrients exist in soil as either complex organic or inorganic compounds that are unavailable to plants or in simple forms that are usually soluble in water and therefore readily available to plants (Table 3). The complex forms, too numerous to mention, must first be broken down through decomposition to simple, soluble forms to be available and therefore useful to plants (Fig. 5).

Table 2 Important growth media properties affected by their structure and texture

Medium	Capillary rise (cm)	Water absorption (%, v/v)	Percolation
Soil	18	21	very slow
Peat-mix	30	27	slow
Vermiculite	29	21	fast
Perlite	41	17	fast
Rock wool	10	17	fast
Expanded clay pellets	2	11	very fast

Table 3 Essential elements for the growth of most cultivated plants

Element	Symbol	Atomic weight	Available from
Organic elements (from air and water)			
Hydrogen	H	1.00	H_2O
Carbon	C	12.00	CO_2
Oxygen	O	16.00	O_2, H_2O
Macronutrients (needed in large quantities)			
Nitrogen	N	14.00	NO_3^-, NH_4^+
Potassium	K	39.10	K^+
Calcium	Ca	40.08	Ca^{++}
Magnesium	Mg	24.32	Mg^{++}
Phosphorus	P	30.92	$H_2PO_4^-$, HPO_4^{--}
Sulfur	S	32.07	SO_4^{--}
Micronutrients (needed in small quantities)			
Iron	Fe	55.85	Fe^{+++}, Fe^{++}
Manganese	Mn	54.94	Mn^{++}
Copper	Cu	63.54	Cu^{++}, Cu^+
Boron	B	10.82	BO_3^{---} $B_4O_7^{--}$
Zinc	Zn	65.38	Zn^{++}
Molybdenum	Mo	95.95	MoO_4^{++}

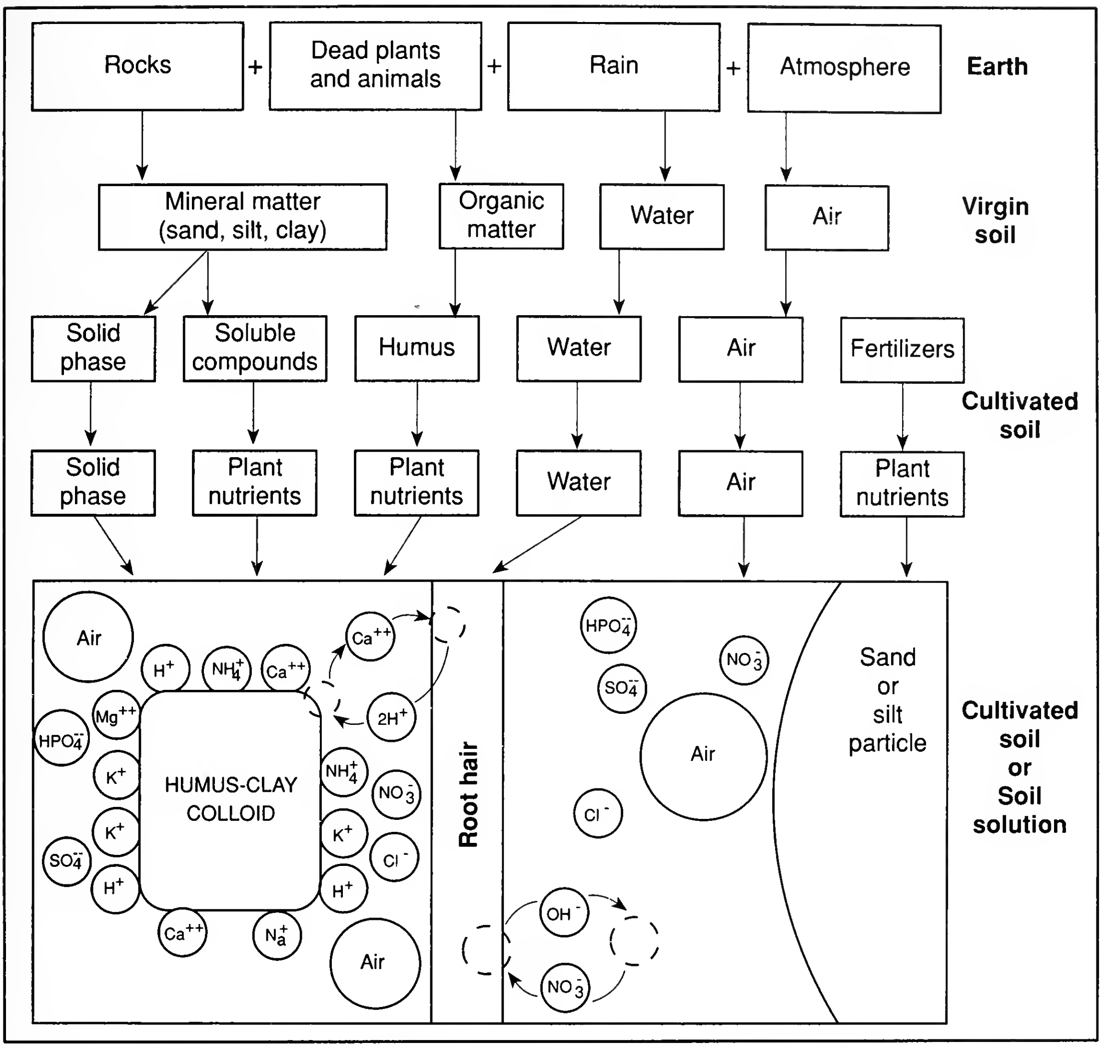

Fig. 5 The process of mineralization, solubilization, cation exchange, and nutrient absorption.

Soil reaction (pH)

The reaction of the soil solution (pH) also affects the solubility of the various nutrients and thus their availability to plants (Fig. 6).

In acid soils (pH < 7) the nutrients calcium and molybdenum are less available, whereas in alkaline soils (pH > 7) the nutrients iron, manganese, and zinc are less available. Excessive amounts of bicarbonate ($HC0_3^-$) may interfere with the normal uptake of certain nutrients. Most nutrients are available when the pH measures between 6 and 7, so most plants grow best in soils of that reaction.

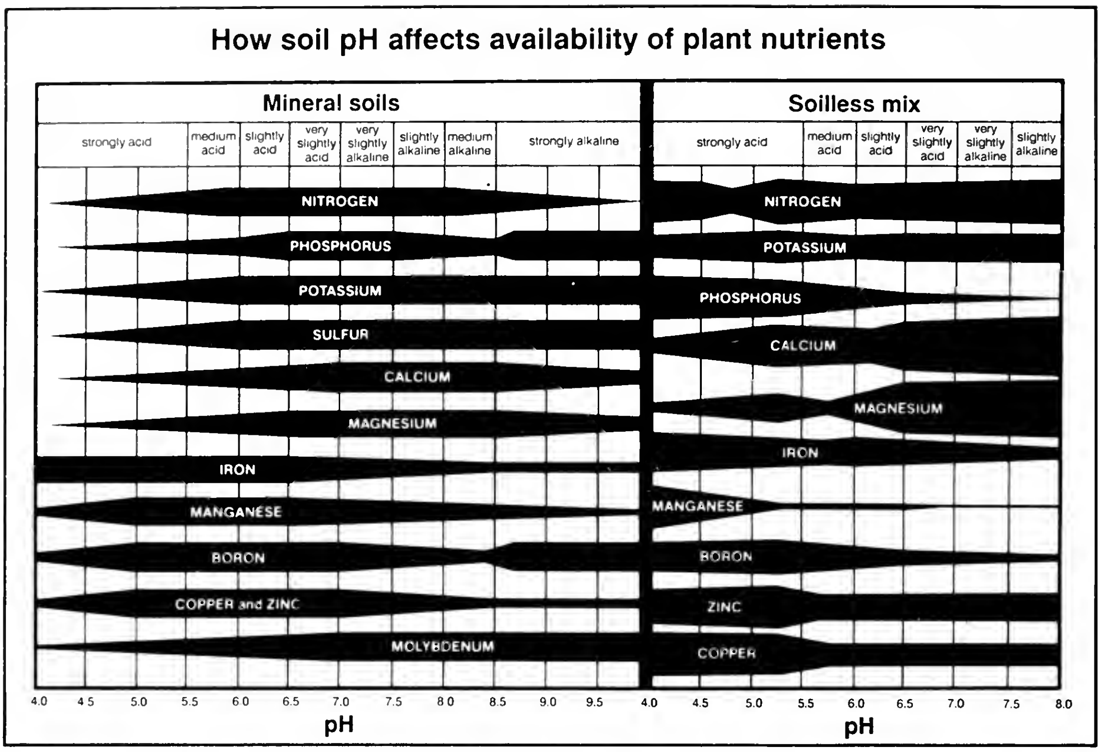

Fig. 6 How soil pH affects availability of plant nutrients (diagram courtesy of Plant Products Ltd.).

Cation-exchange capacity of the soil

When small quantities of inorganic salts such as the soluble mineral matter of soil and commercial fertilizers are added to water, they dissociate into electrically charged units called ions. The positively charged ions (cations), such as hydrogen (H^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), ammonium (NH_4^+), iron (Fe^{++}), manganese (Mn^{++}), and zinc (Zn^{++}), are absorbed mostly on the negatively charged surfaces of the soil colloids (microscopic clay and humus particles). Cations exist only in small quantities in the soil solution. Thus, the humus–clay colloids serve as a storehouse for certain essential cations. The negatively charged ions (anions), such as nitrates ($N0_3^-$), phosphates ($HP0_4^{--}$), sulphates ($S0_4^{--}$), and chlorides (Cl^-), occur almost exclusively in the soil solution. Anions can therefore leach away easily with overwatering. The soil solution bathes the roots and root hairs, which are in intimate contact with the soil colloidal surfaces. Nutrient uptake can take place either from the soil solution or directly from the colloidal surfaces (cation exchange).

The soil solution provides the most important source of nutrients, but it is so dilute that its nutrients are easily depleted and must be replenished from soil particles. The solid phase of the soil, acting as a reservoir of nutrients, slowly releases them into the soil solution by the solubilization of soil minerals and organics, by the solution of soluble salts, and by cation exchange. A more dramatic increase in the nutrient content of the soil solution takes place with the addition of commercial fertilizers.

As plants absorb nutrients (ions) they exchange them for other ions. For example, for the uptake of one potassium (K^+) or one ammonium (NH_4^+) ion, one hydrogen (H^+) ion is released into the soil solution or directly onto the soil colloids through cation exchange. Similarly, for the uptake of one calcium (Ca^{++}) or one magnesium (Mg^{++}) ion, the root releases two hydrogen (H^+) ions. As the plant absorbs these essential cations, the soil solution and the colloidal particles contain more and more hydrogen (H^+) ions. As a result, when crops remove cations (ammonium nitrogen is a good example), soils become more acidic. Also, as the plant absorbs essential anions such as nitrates and phosphates, the soil solution is enriched with more and more hydroxyl groups ($0H^-$) and bicarbonates (HCO_3^-), which explains why the removal of anions (nitrate nitrogen is a good example) by crops makes soils alkaline.

Nutrient requirements and effects

Growing a successful cucumber crop depends on the grower's ability to maintain an optimum balance between vegetativeness and reproductiveness. We judge a well-balanced plant by its thick stem, its large and dark green leaves, and its high number of rapidly sizing-up fruit. A properly nourished and fully developed plant has a main stem about 1.5 cm thick, two main sideshoots about 1.0 cm thick, and at least one fruit set and growing fast (7 days from set to harvest) at each node. Thicker stems indicate overvegetativeness. They are usually associated with profuse fruit setting, which triggers a cycle of overbearing, carbohydrate depletion, retarded root growth and renewal, arrested growth, widespread fruit abortion, and slow recovery. Thinner, slow-growing stems indicate overproductiveness or poor growing conditions. Long, sustained fruit production is not easy, but it can be achieved under optimum environmental conditions and by timely application of water and nutrients. Although inorganic nutrients make up a tiny fraction of the total plant weight ($\simeq$1%), their application, usually as a chemical fertilizer, is vital. Fertilizers influence greatly how the crop grows and develops and ultimately the quantity and quality of fruit relative to other greenhouse crops. Cucumbers are heavy feeders (i.e., they absorb and use large quantities of fertilizers). At the same time they can easily suffer root damage from fertilizer overdose or wide variation in the fertilizer supply. Because cucumbers are highly sensitive to salinity, yield declines inversely as the electrical conductivity (EC) of

the fertigation solution increases. Although the fertilizer feeding program needs adjusting throughout the production season to suit the changing nutritional needs of the crop as environmental conditions change, take care to make any changes small and gradual (Table 4).

Computer-controlled multifertilizer injectors are now used commercially for the precise dosing of fertilizers according to crop needs (Plate II).

The following sections describe the role of each nutrient in the growth and productivity of seedless cucumbers.

Table 4 Content of nutrients in dry matter of leaves from healthy cucumber plants and from plants with deficiency or toxicity symptoms; dry matter ranges from 80 to 110 g kg^{-1}, with 98 g kg^{-1} as an average for fresh leaves

Nutrient element	Health		Deficiency	Toxicity
	Range	Mean		
Nitrogen (mol kg^{-1})				
total N	1.8–3.6	2.96		
nitrate N	0.07–1.0	0.24	<0.07	1.3
Phosphorus (mol kg^{-1})	0.11–0.25	0.17	<0.07	
Potassium (mol kg^{-1})	0.5–1.5	0.97	<0.4–0.5	
Magnesium (mol kg^{-1})	0.2–0.8	0.42	<0.10	
Calcium (mol kg^{-1})	0.5–2.5	1.19	<0.5	
Sulfur (mol kg^{-1})				
total S	0.13–0.30	0.19	<0.08	
sulphate S	0.05–0.28	0.13		
Boron (mmol kg^{-1})	2.8–10.0	7.0	<2.5	>25
Copper (mmol kg^{-1})	0.03–0.30	0.20	<0.03	
Iron (mmol kg^{-1})	1.7–5.4	4.2	<0.9–2.7[a]	
Manganese (mmol kg^{-1})	0.9–11.0	5.8	<0.4–0.7	> ± 10
Molybdenum (mmol kg^{-1})	0.01–0.06	0.032	<0.008–0.010	
Zinc (mmol kg^{-1})	0.9–3.0	0.032	<0.3	> ± 10

[a] Not diagnostic.

Source: Roorda van Eysinga, J.P.N.L.; Smilde, K.W. 1981. Nutritional disorders in glasshouse tomatoes, cucumbers and lettuce. Cent. Agric. Publ. and Docum., Wageningen, The Netherlands. 130 pp.

Macronutrients

Cucumber plants need the following nutrients in large quantities: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur.

Nitrogen

Nitrogen contributes more toward the vegetative organs (leaves and stems) of the plant than the fruit. High rates of nitrogen induce vigorous vegetative growth to the ultimate detriment of fruit and root growth. The ammonium form of nitrogen particularly encourages vegetative growth. Ammonium nitrate, or urea, applied at low, well-planned and regulated concentrations can effectively invigorate a weak, stagnant crop. However, because a high danger of burning the crop exists with such fertilizers, exercise great caution (Plate III*a–d*). Seek expert opinion in advance. The early symptoms of ammonia injury are small chlorotic spots on the leaves; these later increase in size and merge leaving only the veins green. Refer to the specific guidelines for fertilizer application rates according to each cropping system, as listed later.

Deficiency A nitrogen deficiency expresses itself in hard plants with woody stems in small and thin leaves and a general pale color on foliage. Nitrogen being a mobile nutrient within the plant, symptoms of yellowish green appear first on older leaves. Eventually, the entire plant turns pale green and the younger leaves stop growing. The fruit becomes short, thick, light green, spiny, and occasionally constricted at the distal end.

Toxicity An excess of nitrogen is expressed by strong thick stems, deep green curly leaves, short internodes, and a profusion of tendrils, short side shoots, and flowers (or small fruit). In severe cases, growth stops, middle and lower leaves curl and drop slightly, and transparent spots appear between the veins, which later turn yellow and brown. Eventually marginal and interveinal chlorosis turns into leaf scorching and the entire plant collapses. In most cases, the plants can be saved, provided they have not wilted permanently, by heavy irrigation and restricting transpiration through appropriate environmental control.

Concentration Normal levels of nitrogen in plant tissue are 5–6% N in the dry weight of the third leaf from the top (10 cm in diameter), or, 0.5–1.5% NO_3 in the dry weight of fully developed young leaves, or, 2–3% N (or 0.6–1.2% NO_3) in the sap of mature petioles. Nitrogen-deficient plants contain nitrogen at less than 3% or 2% in the dry weight of young and old leaves, respectively.

Correction Correct a nitrogen deficiency with a foliar spray of urea dissolved in water at 2–5 g L^{-1}; to avoid leaf scorching, ideally spray either under cloudy weather or late in the afternoon or remove the residues from foliage with water. Immediately seek a permanent correction of the deficiency; identify the cause of the problem and apply the appropriate

amount of nitrogen fertilizer regularly, depending on the production system.

Phosphorus

Although phosphorus is used in much smaller quantities than nitrogen its presence is also needed continuously. Initially, phosphorus is important for early root growth, especially under cool root conditions, but it also has a profound effect on vegetative growth and fruit production throughout the entire season. Phosphorus stores well in soil but leaches easily from peat and soilless media. Therefore phosphorus must always be included in the feed of all soilless media.

Deficiency Phosphorus deficiency is initially expressed as restricted overall growth with no characteristic symptoms. In severe cases, the plants are stunted and the young leaves become small, stiff, and dark grayish green; the older leaves develop large water-soaked spots over both the veins and the interveinal areas. Eventually the affected leaves fade, shrivel, turn brown, and desiccate.

Toxicity Phosphorus toxicity is uncommon.

Concentration Normal levels of phosphorus in plant tissue are 0.6–1.3% P in the dry weight of main stem leaves; more phosphorus is found in young leaves; the third leaf below the top with an approximate diameter of 10 cm is the standard for sampling. Phosphorus-deficient plants contain less than 0.3% or 0.2% P in the dry weight of young and old leaves, respectively.

Correction Correct a phosphorus deficiency by adding fertilizer to the soil (e.g., triple superphosphate at 20 g m^{-2}) or in the irrigation water (e.g., 30–50 ppm P as monopotassium phosphate).

Potassium

Plants need potassium, which is mobile in the plant, in large quantities; it is essential for normal growth and high fruit quality. As a major nutrient with a positive charge, it plays a major role in balancing the negative charges of organic acids produced within the cell and of other anions such as sulphates, chlorides, and nitrates. Potassium also activates several enzymes and controls transpiration by affecting the opening and closing of stomates. The effects of potassium supply depend on interactions with several elements. In general, nitrogen and phosphorus have antagonistic effects and induce or accentuate potassium deficiency. Calcium (and to a smaller extent magnesium) antagonize potassium uptake, but severe calcium deficiency can also bring potassium deficiency. Ammonium greatly decreases the rate of potassium uptake. Potassium deficiency tends to induce or accentuate iron deficiency.

Deficiency Symptoms of potassium deficiency appear first on older leaves (which remain the worst affected) and progress from the base towards the top of the plant. In general, growth is stunted, internodes are short, and leaves are small. Chlorosis almost always occurs first at the margins of older leaves, which often curve downwards. Later, chlorosis moves into the interveinal areas towards the centre of the leaf, and necrosis of the leaf margins follows. Although leaf margins desiccate, the veins remain green for some time. Fruit might appear with enlarged tips but underdeveloped at the stem end. Potassium deficiency is rare in soil culture (except in sandy soils). However, it can develop quickly in soilless culture when the potassium supply in the nutrient solution is inadequate.

Toxicity Excess potassium rarely presents a problem unless it induces the deficiency of other nutrients (e.g., calcium, magnesium, iron).

Concentration Normal levels of potassium in plant tissue are 4 ± 1% K in the dry weight of a young (10 cm in diameter) leaf laminae (the petioles contain far higher levels, e.g., 8–15% K), and 3500–5000 ppm K in the petiole sap. Deficiency symptoms and loss of yield can be expected if the potassium content in leaf laminae drops below 3.5% (dry weight), or below 3000 ppm K in the petiole sap.

Correction Correct a deficiency by ensuring a good supply of potassium either in the soil as a base dressing (e.g., apply potassium at 80 g m^{-2}), or in the water supply as a liquid feed (e.g., apply 300–500 ppm K). For immediate results, the crop may also be sprayed with a solution of potassium sulphate in water at 20 g L^{-1}. However, not all the potassium needs of a crop can be supplied through sprays.

Calcium

Calcium moves in the xylem along with the water, and little translocation occurs from the older to the younger leaves. Therefore, when the supply of calcium is interrupted or low, deficiency symptoms appear first at the top of the plant. Calcium is of great importance to the structure and stability of cell membranes and to the stability and rigidity of cell walls.

Deficiency Calcium deficiency is uncommon in cucumbers, other than under continuously humid conditions in well-sealed energy-efficient greenhouses. At the initial stages of calcium deficiency, the youngest leaves show transparent white dots near the edges and between the veins. Interveinal chlorosis is common, while the veins stay green. Plants stop growing and the internodes are short especially near the apex. The younger leaves remain small with their edges curled characteristically upwards. Older leaves, though, curl downwards. In severe cases, petioles become brittle and leaves drop easily, flowers abort, and the growing point of the plant dies back. The roots of calcium-deficient plants are also poorly developed, thicker, and shorter than normal; they usually turn brown and have few root hairs. The fruits are small and tasteless and fail to develop

normally at the blossom end. The complex interactions and antagonisms of calcium with other cations are discussed under "Potassium." A calcium deficiency could develop on soils where leaching depletes calcium reserves, in unlimed peat, or in soilless culture where the nutrient solution contains insufficient calcium.

Concentrations Normal levels of calcium in plant tissue are 1.5% Ca in the dry weight of young leaves (10 cm in diameter), or, 5.0% Ca in the dry weight of young fully developed leaves. Deficiency symptoms begin to appear when calcium drops below 0.5% in the dry weight of young (10-cm) leaves.

Correction To correct calcium deficiency quickly, spray plants with a solution of calcium nitrate in water at 10 g L^{-1}, preferably under cloudy conditions or late in the day to avoid salt burns on foliage. Permanent correction is possible only by identifying the cause of inadequate calcium uptake and fixing the problem.

Magnesium

Deficiency Magnesium deficiency expresses itself first with mottled chlorosis and brown spotting on the lower leaves. Yellow spots initially appear in interveinal areas, while the veins remain green. A green margin might remain around the leaf even in severe cases where the yellow interveinal areas have dried out to a pale brown. In soil culture, magnesium deficiency usually exists only in the plant, not in the soil. The deficiency might be related to high potassium (from excessive potassium fertilizer dressings), or calcium (from excessive liming), or ammonium, or unfavorable (low) soil pH. These conditions make it difficult for the plant to take in sufficient magnesium, thereby forcing it to move magnesium from the older to the new leaves. The deficiency also develops in soilless culture if the magnesium in the nutrient solution is allowed to drop to the minimum recommended level or to go out of balance with the other cations (i.e., K^+, Ca^{++}, NH_4^{++}, H^+).

Toxicity Magnesium toxicity symptoms, consisting of marginal scorching on dark green leaves, are rare. They appear in soilless culture if the magnesium concentration in the nutrient reaches extremely high levels.

Concentration Normal levels of magnesium in plant tissue are 0.5–0.7% Mg in the dry weight of young leaves (10 cm diameter) but higher in older leaves (e.g., 0.5–0.9% Mg in young leaves, or 1.5–2.0% Mg in old healthy leaves). Deficiency symptoms appear when magnesium in the young leaves (10 cm diameter) falls below 0.35% (dry weight).

Correction Correct a magnesium deficiency with high-volume sprays of magnesium sulfate in water at 20 g L^{-1}, preferably during cloudy weather or late in the day to avoid salt burns on foliage. Even better, ensure the

proper magnesium supply reaches the roots, depending on cropping system.

Sulfur

This element is rarely in deficiency because it is present in many fertilizers as a carrying element and because it exists as a common pollutant. However, high sulfur levels can produce excessive salt levels and can be detrimental to the uptake of molybdenum.

Micronutrients

Cucumber plants need the following nutrients in small quantities: iron, manganese, copper, boron, zinc, molybdenum, and chlorine.

Iron

A small quantity of iron is essential for chlorophyll synthesis. Iron is immobile in the plant.

Deficiency Deficiency symptoms resemble those of magnesium deficiency but appear almost always as chlorosis of the young, rapidly expanding leaves. At first, the youngest leaves become yellow-green or yellow, but the veins remain green. Later, chlorosis spreads to veins, first to the smaller ones, and affected leaves turn lemon yellow to white. Shoots then stop growing, and necrosis appears on leaves that have lost chlorophyll completely. Side shoots and fruit also show deficiency symptoms.

As with calcium deficiency, in most cases iron deficiency is induced. Indirect causes of iron deficiency may be

- too high pH in the medium
- too much manganese in the medium
- anaerobic conditions in the medium
- poor root growth
- root death in NFT or overwatered media.

In many cases, improved oxygenation of the roots, by improving media texture and structure, optimizing irrigation, aerating media and nutrient solutions, and ensuring sufficient plant transpiration rates, corrects the problem.

Toxicity An iron overdose (toxicity) usually expresses itself as a manganese deficiency, which indicates further the strong competition between iron and manganese in the plant.

Concentration The normal concentration of Fe in plant tissue is 100–300 ppm in the dry weight of fully expanded leaves (fifth leaf from the top). Deficiency symptoms appear when this concentration drops

below 50 ppm, although chlorosis may also occur when the Fe content exceeds 100 ppm. This discrepancy occurs because not always is all iron in the plant tissue physiologically active.

Correction When the nutrient supply itself is the limiting factor, apply iron salts or iron chelates to the soil (Fe-EDDHA at 5–10 g m^{-2} or Fe-DPTA at 12–20 g m^{-2}) or use foliar sprays (Fe-EDTA in water at 0.2 g L^{-1}). However, the best action is to eliminate the source of the problem. Contrary to general opinion, iron chelates are toxic to plants at high concentrations, so do not exceed the recommended rates, particularly for the foliar sprays. Also do not use foliar sprays frequently, because salts can accumulate on the foliage and, over time, become toxic. To enhance the nutrient absorption and reduce the risk of salt burn, try to spray under cloudy conditions or late in the afternoon. To avoid stem rots, direct spray only at the top part of the plants where the deficiency symptoms show.

Manganese

The plants need manganese, in minute quantities, to activate several enzymes. The most important of these promote photosynthesis and the production of the plant hormone auxin. Without manganese, hydrogen peroxide accumulates in the cells and damages them. Like iron, manganese is immobile within the plant, accumulating mostly in the lower leaves.

Deficiency Frequently confused with iron deficiency, true manganese deficiency is rare. In fact, because of the usual competition between iron and manganese, an apparent manganese deficiency may be an expression of iron toxicity. Manganese deficiency symptoms appear mostly on new growth. Diagnosing the actual nutritional disorder is often not easy, because symptoms among iron deficiency, iron toxicity, and manganese deficiency appear similar.

The most characteristic distinguishing feature of manganese deficiency, as compared to iron deficiency, is that, although the margin and interveinal parts of the leaf become progressively pale green, yellow-green, and yellow, the veins remain green. Manganese deficiency in leaves is also distinguishable by the appearance of characteristic necrotic spotting or lesions. At advanced stages, the entire leaf, with the exception of the main veins, becomes yellow, and whitish sunken areas develop between the veins. Manganese deficiency occurs on calcareous soils, on heavily limed peat media, or in soilless media when the nutrient solution contains no manganese.

Toxicity Manganese toxicity symptoms, pale green and yellow areas between the veins, appear first on the oldest leaves. The veins turn red-brown, and numerous purple spots develop on the stems, petioles, and veins on the underside of the leaves.

Manganese toxicity usually follows steaming of soil. It occurs particularly in acid soil, or when steaming is prolonged or carried out at too high a temperature, or when leaching of the soil after steaming is inadequate.

Concentration The normal concentration of manganese in young leaves is 30–60 ppm, and in older leaves 100–250 ppm. When the manganese concentration in young leaves drops below 50 ppm, loss in yield may occur; when it drops to 12–15 ppm, deficiency symptoms generally appear. Toxicity symptoms appear when the manganese content reaches 500–800 ppm in young and old leaves, respectively. Expect significant yield loss if the manganese concentration reaches 2000–5000 ppm in young and old leaves, respectively.

Correction Deficiency symptoms disappear quickly after foliar application of manganese sulfate at 1.5–10 g L^{-1} as high- or low-volume spray, respectively. Generally, nutrient solutions should contain 0.05 ppm Mn. In soil, apply manganese sulfate at 50 g m^{-2} as a long-term remedy to manganese shortage, along with measures to lower the soil pH, if higher than normal.

Copper

Several enzymes with diverse properties and functions depend on copper, including those involved in photosynthesis and respiration. Although copper is mobile in plants well supplied with the element, it is much less mobile in deficient plants. Therefore copper concentration in young developing tissue is likely related to plant status. However, soil analysis is a more useful guide to copper deficiency than tissue analysis.

Deficiency Copper deficiency restricts growth and causes short internodes and small leaves. Initially, interveinal chlorotic blotches appear on mature leaves, but later symptoms spread upwards on the plant. The leaves eventually turn dull green or bronze, their edges turn down, and the plant remains dwarfed. Furthermore, bud and flower development at the top of the plant decreases. The few fruits that are produced develop poorly with small, sunken brown areas scattered over their yellow-green skin.

Copper deficiency is unusual, partly because the widespread use of copper in plumbing and in fungicides ensures an adequate supply in most cases. Occasionally it becomes a problem with crops in peat media or in all-plastic hydroponic systems when no copper is added to the nutrient solution. High soil pH reduces available copper, but this effect is much smaller than for manganese, iron, and boron.

Toxicity Copper toxicity, although rare, can appear as an induced iron chlorosis, where the soil is contaminated with copper either from industrial sources or after repeated spays of copper-containing fungicides. Toxic effects persist, and the only partial solution is heavy

liming. In hydroponic systems, extensive use of copper plumbing can produce copper contamination.

Concentration Normal levels of copper in the dry weight of the first fully expanded leaf (fifth leaf) range from 8 to 20 ppm. Deficiency symptoms start appearing when the copper concentration falls below 7 ppm and become severe at 0.8–2.0 ppm. Copper deficiency can dramatically reduce yield (20–90%).

Correction To prevent copper deficiency in peat media, where it is most common, add copper sulfate at 10 g m^{-3}, as a precaution. Generally, nutrient solutions should contain 0.03 ppm Cu. For quick results, spray plants with a solution of copper sulfate using up to 1 g L^{-1}, plus calcium hydroxide (approx. 0.5%) for pH adjustment.

Boron

The specific biochemical function of boron in plants is not known, but it is generally believed that this element is essential for some processes of cell division and differentiation in apices (growing points). Boron is not mobile within the plant. A continuous supply of this nutrient to the roots is essential for healthy growth. The availability of boron is lowest in sandy soils at high pH. The quality of water also determines the boron status of the plants.

Deficiency Deficiency symptoms appear at growing points and in reproductive organs. Symptoms appear around the first harvest when middle and lower leaves become slightly chlorotic and brittle. Although the most characteristic effect of boron deficiency is the death of the stem apex (growing tip), other effects include

- growth of axillary buds and bushy appearance of plants
- malformed young leaves with prominent veins and cupped stiff older leaves
- cupped upwards brittle leaves of reduced size
- yellowing of the lower leaves developing broad cream margins and eventually becoming brown and curling downwards and inwards
- short fruit with longitudinal cracks in the skin
- blackened roots with enlarged root tips.

Severe boron deficiency can lead to serious yield losses (up to 90%) and fruit quality deterioration.

Toxicity The narrow margin between deficiency and toxicity causes a particular problem with boron. The cucumber plant is particularly sensitive to high levels of boron in the substrate, or in the water supply (>1 ppm B). Because boron tends to be immobilized in the plant, boron toxicity symptoms appear first on older leaves. Careless use of boron fertilizers easily causes boron toxicity. Initially, the edges of older leaves

turn yellow-green, cup downward, and grow more circular than usual. Later the symptoms progress from the base of the plant upwards, and necrotic spots develop between the veins. Eventually, growth becomes stunted, upper leaves remain small, and few female flowers develop.

Concentration The normal level of boron in the dry weight of leaves varies from 30 to 120 ppm. Deficiency symptoms appear when the content falls as low as 6–8 ppm B (top leaves) or <20 ppm B (bottom leaves). Toxicity symptoms appear when the content exceeds 250–300 ppm B (top leaves) or 500–1000 ppm B (bottom leaves).

Correction Boron deficiencies are easily corrected by adding sodium borate to the soil at 2 g m^{-2} or by spraying with sodium borate in water at 1–2 g L^{-1}. Boron toxicities are harder to correct. Heavy leaching of sandy soils and liming of acid soils may be effective.

Zinc

Several enzymes present in plants contain zinc. Of all micronutrients, zinc, when deficient, has the most obvious effect on photosynthesis. However, this element is rarely deficient.

Deficiency Deficiency occurs when hydroponically grown plants have no zinc in the nutrient solution. The normal zinc content of soils usually falls in the range of 10–300 ppm Zn.

Zinc in soils becomes less available as the soil pH rises and in the presence of calcium carbonate. A heavy application of phosphorus can induce zinc deficiency because insoluble zinc phosphates form. Copper and possibly iron, manganese, magnesium, and calcium hinder the uptake of zinc.

The symptoms of deficiency are not well defined, but usually a slight interveinal mottle develops on the lower leaves that spreads up the plant. The upper internodes remain short. Small leaf size most characterizes zinc deficiency; in severe cases, short internodes cause the top of the plant to grow bushy. Overall growth is restricted and the leaves become yellow-green to yellow except for the veins, which remain dark green and well defined.

Toxicity The potential for zinc toxicity exists where galvanized pipes release zinc. Toxicity occurs in soils contaminated by their proximity to zinc smelters and mines and in greenhouses with galvanized frames and plumbing. In the case of zinc toxicity, the entire veinal network, initially dark green, becomes somewhat blackened. The blackish appearance of the main veins helps distinguish zinc toxicity from manganese deficiency in which the veins remain green. In severe cases of zinc toxicity the young leaves become yellow and the symptoms resemble those of iron deficiency.

Concentration The normal concentration in the dry weight of the fifth leaf ranges from 40 to 100 ppm Zn. Symptoms of deficiency appear when

the concentration drops below 20–25 ppm Zn. Toxicity can be expected when the zinc concentration exceeds 150-180 ppm (old leaves) or 900 ppm (tops of plants).

Correction Spraying with zinc sulphate (5 g L^{-1}) easily corrects a zinc deficiency. Applying lime or phosphate sometimes reduces a zinc toxicity.

Molybdenum

Molybdenum is involved in many enzymes and is closely linked with nitrogen metabolism. Plants need tiny amounts of molybdenum—an average 0.2 ppm Mo available in soils is adequate. Molybdenum is present in soil as an anion, in contrast to most other micronutrients, which are present as cations. It behaves like phosphate. The availability of molybdenum increases as the pH rises and therefore a deficiency of this element is more likely to occur in acid (and sandy) soils, in which case liming might be helpful.

Deficiency Molybdenum deficiencies are rare, but have been observed in plants growing in peat. Initially, the green of the leaves fades, particularly between the veins. Later, leaves can turn yellow and die. In some cases, parts of mature leaves remain green at first, giving rise to a blotchy appearance. Symptoms start first in lower leaves and spread upwards, the younger ones remaining green. Growth might appear normal but flowers stay small. Severe deficiency cases in peat can significantly reduce yield (up to 84%), but raising the pH (up to 6.7) through liming restores yield to near normal.

Toxicity While plants can take up high levels of molybdenum without harmful effects on growth, there might be concern for health with high molybdenum levels in the produce.

Concentration The normal concentration in the dry weight of leaves is 0.8-5.0 ppm Mo. Deficient plants contain less than 0.3 ppm Mo.

Correction As a preventative measure on peat, apply sodium molybdate at 5 g m^{-3}. Treat a deficiency either by applying sodium molybdate to the soil at 150 mg m^{-2} or by spraying with a solution of sodium molybdate in water at 1 g L^{-1}.

Chlorine

Chlorine is the latest addition to the list of elements considered essential for plant growth. Deficiency of chlorine has never been encountered other than in strictly controlled experiments, because of the prevalence of the element in the environment as a contaminant.

Toxicity Excess chlorine is a serious concern, especially in recirculated hydroponic systems. Normal growth requires only small quantities of chlorine (similar to iron), but if the supply is plentiful more is taken up. The large quantities of chlorine found in various fertilizers as a carrying element can easily result in toxic levels of chorine accumulating in the recirculating solution.

Concentration For rock-wool culture, in particular, the recommended maximum concentration of chlorine in the nutrient feed is 35 ppm Cl; the corresponding maximum in the rock-wool slab is 70 ppm Cl. However, recent experience suggests that these levels may have been underestimated.

Nonessential elements

The following elements are potentially useful, or harmful: silicon and sodium.

Silicon

Silicon exists as one of the most abundant elements in soils, most of it tied up in quartz. Available silicon is present as monosilisic acid [$Si(OH)_4$] and decreases with increasing pH.

Although we lack absolute evidence that silicon is an essential element, evidence mounts that it is beneficial in many ways. Silicon often appears stimulatory, but its abundance in dust makes the study of its effects on yield difficult.

The amendment of hydroponic nutrient solutions with 75–100 ppm of soluble silica (SiO_2) has been reported to result in improved yields and reduced powdery mildew and pythium root rot. Add potassium or sodium silicate continuously.

Sodium

Sodium may not be essential for plant growth, but many plants clearly benefit from sodium when potassium is deficient. Sodium may substitute for potassium in certain instances. It becomes interesting to know what is the upper limit of sodium concentration in nutrient solutions prepared with mildly saline water. In the case of rock-wool culture, a maximum concentration of 23 ppm Na is recommended for the nutrient feed and 46 ppm Na in the rock-wool slabs.

General cultural practices

Crop scheduling

Early spring crop

- Sow seed 15 November–15 December
- Set plants in permanent bed 20 December–20 January
- Harvest February to July
- Remove plants 1 July–20 July
- Sterilize soil, general clean-up 1 July–25 July.

Late spring crop

- Sow seed 15 December–30 January
- Set plants in permanent bed 20 January–1 March
- Harvest March to July
- Remove plants 1 July–20 July
- Sterilize soil, general clean-up 1 July–25 July.

Fall crop

- Sow seed 20 June–July 15
- Set plants in permanent bed 15 July–August 15
- Harvest 15 August–15 December
- Remove plants 15 November–15 December
- Sterilize soil, general clean-up 16 November–31 December.

Sometimes the spring crop, either early or late, can extend up to the following November if plants are healthy and price holds well through the summer months. A spring or fall crop may also be replaced by a corresponding tomato crop.

In rare instances, even dedicated tomato growers will raise a summer cucumber crop as a quick fix to revenue loss caused by premature termination of a spring tomato crop.

Cultivar selection

A large selection of seedless cucumber cultivars exist in the international market, and many more are introduced every year. Many seed suppliers are from The Netherlands, and most have local representatives in Canada. The main criteria in selecting the best cultivar are

- overall productivity
- plant growth habit and vigor
- fruit quality (i.e., length, diameter, shape, color, and smoothness)
- fruit shelf life

- disease resistance
- energy requirements.

Only gynoecious types, or predominantly gynoecious types (i.e., with few male flowers) rather than the old-fashioned monoecious types (i.e., with both male and female flowers) are acceptable. The gynoecious cultivars are preferred because they are less vigorous (and therefore require less pruning), come into production earlier, produce more, and can grow at lower temperatures. The choice of cultivar is a complicated decision based on published research findings and growers' experience with the various cultivars available. The situation is further complicated because, depending on the crop management strategy followed, different growers can receive equally satisfying results with different cultivars. The existence of a large number of cucumber breeding houses guarantees that, at least for the foreseeable future, a good selection of high-quality cucumber cultivars will continue to be available. For reasons that have to do with the intrinsic benefits of hybridization and the protection of the commercial rights of the breeding houses, nearly all seedless cucumber cultivars on the market are sterile hybrids (i.e., it is not possible to save seed from the previous crop).

At the time of writing the most popular cultivars are Corona, Jessica (mostly a fall favorite), Bronco, Ventura, and Dugan. The recent introduction of new cultivars (e.g., Aramon and Flamingo) with powdery mildew tolerance, and possibly some form of resistance, has raised expectations for improved overall disease resistance. However, until now, those cultivars having powdery mildew tolerance appear disadvantaged by inferior vigor and productivity.

Contact your local horticultural crop adviser for current advice on recommended cultivars.

Plant propagation

Most greenhouse operators in Canada grow their own transplants. This practice reduces the possibility of importing diseases and insects. However, some specialized nurseries in other countries have ensured a reliable supply of low-cost high-quality transplants to local growers by applying modern technology. Plant propagation is a vitally important stage in greenhouse vegetable production. The success of a crop depends largely on the attention paid to detail and the care taken during plant raising. Moreover, with early spring crops, propagation must take place in the winter, when natural light is limited. To make the best use of available light, other factors such as spacing, temperature, irrigation, and nutrition must be closely and accurately controlled. Artificial light, now used widely to enhance transplant growth when natural radiation is limited, significantly improves the performance of early-planted spring crops.

The preferred way of raising cucumber transplants is to sow the seed in small multicell propagation trays and then transfer the seedlings into

larger pots for finishing until final planting into the greenhouse. An alternative way is to sow the seed directly in the large pots (or rockwool blocks) and to bypass the first stage. The first method, because the trays take less space than the pots, costs less to provide with the required high temperature before germination and the high light intensity after germination. The second method saves the labor cost for transferring the seedlings from the trays to the pots. Base your choice of method on the relative cost and availability of labor, energy, and proper facilities.

Propagation schedules

In deciding when to seed, consider the desired harvesttime. It usually takes 8–10 weeks from seed to first pick in a normal spring crop but only 7–8 weeks in a normal fall crop. A spring crop that comes into production at the beginning of February requires seeding to take place around the end of November. In recent years, an increasing number of growers plant a late spring crop in plastic houses. In that case, seeding takes place in January and planting in-house in February. Harvest occurs during March to July, and later. The late spring crop is easier and less expensive to grow but comes into production when prices are relatively low. For an average fall crop, seed normally in the 1st week of July.

Seed sowing and seedling establishment

Each gram contains about 28 seeds. To achieve a planting density of 14 000 plants per hectare, assuming a germination rate of 90% and a safety margin of an additional 10% transplants, sow seed at about 600 g ha^{-1}.

Because of a peculiarity in the way the root of the cucumber plant (and other cucurbitaceae) develops, it is unacceptable to raise seedlings in flats, or in some other way that involves pulling the seedlings and damaging their roots. Instead, multicell trays (e.g., plug trays or plug strips) must be used throughout the entire propagation cycle so that plants can be transferred in their entirety with their root systems intact.

Soil and soilless mixes

Select a medium for seedlings that matches the growth medium to be used for growing the crop. Steamed and subsequently leached soil (preferably sandy-loam) is recommended for soil-based operations; a proven commercial or a home-made peat mix (Table 5) is recommended if you choose to grow the crop in peat-bags. Start by filling a plastic tray (55 × 27 cm) divided in individual cells with approximate cell size of 3 × 3 cm (plug trays or plug strips are convenient, and widely available).

Table 5 Ingredients of a standard peat-mix for raising cucumber seedlings

Medium	Amount
Peat	1.0 m^3 (4 bales of 0.17 m^3)[a]
Horticultural vermiculite	0.5 m^3 (4.5 bags of 0.11 m^3)
Limestone (pulverized FF)	10 kg

[a] Expansion of compressed bales is estimated at 50% over the original volume.

Press the growth medium into the tray cells with a second tray, to create space (impressions of 1.5–2.0 cm) for sowing the seed. Place one seed per cell at least 1 cm below the surface of the medium. Add more medium over the seed and use a ruler or other similar object to strike off any excess medium. When soil or peat is the growth medium, apply only water after sowing the seed; ideally, cover the trays with a thin plastic film to conserve moisture. After germination and until seedlings are transferred to pots, add plain water, or very dilute fertilizer solution as needed (overall EC of about 1200 $\mu S\ cm^{-1}$; see recommendations in Tables 6 and 7).

Table 6 Stock solutions required for the preparation of complete nutrient solutions for cucumber transplants in soil and soilless mixes

Fertilizer[a]	Salt in stock (kg 1000 L^{-1})
Stock A	
Calcium nitrate	67.0
Potassium nitrate	74.0
Stock B	
Potassium sulphate	13.5
Stock C	
Monopotassium phosphate	22.5
Magnesium sulphate	50.0
Micronutrient mix[b]	2.0

[a] The stock solutions can be used, as described in Table 7, to prepare nutrient solutions of various ECs for raising transplants in soil and soilless mixes.

[b] A typical micronutrient mix (e.g., Plant Product Chelated Micronutrient mix) contains 7% Fe, 2% Mn, 0.4% Zn, 0.1% Cu, 1.3% B, and 0.06% Mo.

Table 7 Amount of each stock solution required to prepare 1000 L of final nutrient solution with various conductivities for raising cucumber transplants in soil or soilless media, and corresponding nutrient concentrations

	Target EC in final nutrient solution ($\mu S\ cm^{-1}$)[a]				
	1000	1500	2000	2500	3000
	Volume of each stock to be added ($L\ 1000\ L^{-1}$ of final solution)				
Stock A	3.8	5.8	7.5	9.0	12.0
Stock B	3.8	5.8	7.5	9.0	12.0
Stock C	3.8	5.8	7.5	9.0	12.0
	Anticipated nutrient concentrations in final solutions (ppm)				
Nitrogen (NO_3^-)	73	112	145	174	232
Nitrogen (NH_4^+)	3	4	5	6	8
Phosphorus	19	29	37	45	60
Potassium	152	232	300	360	480
Calcium	48	74	95	114	152
Magnesium	19	29	37	45	60
Iron	0.53	0.81	1.05	1.26	1.68
Manganese	0.15	0.23	0.30	0.36	0.48
Zinc	0.030	0.046	0.060	0.072	0.096
Copper	0.008	0.012	0.015	0.018	0.024
Boron	0.099	0.151	0.195	0.234	0.312
Molybdenum	0.004	0.007	0.009	0.011	0.144

[a] The EC of the water has not been included; to obtain the final EC of the nutrient solution add to the ECs listed the EC of your water source (e.g., if your water has an EC of 400 $\mu S\ cm^{-1}$ and you add 7.5 L of each stock to 1000 L of water then your final nutrient solution will have an EC of 2400 $\mu S\ cm^{-1}$).

Rock-wool multiblocks

In the case of rock wool and various other soilless systems, sow the seed and raise the seedlings in special rock-wool multiblocks. These small blocks (e.g., 3.6 × 3.6 × 4.0 cm) are held together as slabs of the same size and shape as the common plastic tray. Each comes with the necessary cavity for placing the seed, but, on delivery from the factory, their pH is too alkaline for immediate use. Start by soaking the multiblocks in nutrient solution with an overall EC of 1500 $\mu S\ cm^{-1}$ and a pH of 5.0–5.5. Tables 8 and 9 give the recommended nutrient concentrations as well as the quantities of fertilizer needed for preparing the nutrient solution for soaking fresh rock wool.

Table 8 Stock solutions required for the preparation of complete nutrient solutions for cucumber transplants in rock wool

Fertilizer	Salt in stock (kg 1000 L^{-1})
Stock A[a]	
Calcium nitrate	100
Potassium nitrate	45
Stock B[a]	
Monopotassium phosphate	22
Magnesium sulphate	33
Micronutrient mix[b]	2

[a] The stock solutions can be used, as described in Table 9, to prepare nutrient solutions of various ECs for raising transplants in rock wool.

[b] A typical micronutrient mix (e.g., Plant Product Chelated Micronutrient mix) contains 7% Fe, 2% Mn, 0.4% Zn, 0.1% Cu, 1.3% B, and 0.06% Mo.

Table 9 Amount of each stock solution required to prepare 1000 L of final nutrient solution with various conductivities for raising cucumber transplants in rock-wool blocks, and corresponding nutrient concentrations

	Target EC in final nutrient solution (µS cm^{-1})[a]				
	1000	1500	2000	2500	3000
	Volume of each stock to be added (L 1000 L^{-1})				
Stock A	5.0	8.5	12.0	16.0	19.0
Stock B	5.0	8.5	12.0	16.0	19.0
	Anticipated nutrient concentrations in final solutions (ppm)				
Nitrogen (NO_3^-)	101	172	244	325	386
Nitrogen (NH_4^+)	5	8	12	16	19
Phosphorus	25	42	60	80	95
Potassium	117	200	282	376	446
Calcium	95	161	228	304	361
Magnesium	16	28	40	53	63
Iron	0.7	1.2	1.68	2.24	2.66
Manganese	0.2	0.34	0.48	0.64	0.76
Zinc	0.04	0.068	0.096	0.128	0.152
Copper	0.01	0.017	0.024	0.032	0.038
Boron	0.13	0.221	0.312	0.416	0.494
Molybdenum	0.006	0.010	0.014	0.019	0.023

[a] The EC of the water has not been included; to obtain the final EC of the nutrient solution, add to the ECs listed the EC of your water source (e.g., if your water has an EC of 400 µS cm^{-1} and you add 8.5 L of each stock to 1000 L of water then your final nutrient solution will have an EC of 1900 µS cm^{-1}).

Sowing the seed entails placing one seed in each cell cavity and covering it with fine vermiculite; this process can easily be automated. The seed covering has been omitted in some cases without any loss in germination, but such practice is not recommended; under certain conditions uncovered seed might dry out before germination or be eaten by small animals.

After the seed germinates, monitor the moisture content in the rockwool and apply nutrient solution with an overall EC of 1500–1800 $\mu S\ cm^{-1}$ and a pH of 5.5, according to need. Judge the need to apply more nutrient solution by how easily you can squeeze nutrient solution out of the rock wool and by the EC of that nutrient solution.

Monitor the EC and pH of the nutrient solution in the rock wool by extracting samples of the solution frequently and testing them with portable EC and pH meters. Maintain the EC and pH below 2500 $\mu S\ cm^{-1}$ and 6.0, respectively, by always applying fresh nutrient solution, in excess of that required to wet the rock wool. Leaching excess nutrients from the rock wool by applying excess nutrient solution is an effective technique for avoiding salt accumulation and seedling damage from too high an EC, but it results in fertilizer waste and must be used responsibly.

Environment control during seedling establishment

Regardless of the growth medium, place the trays with seed in a small greenhouse or special propagation room (no light is needed at this stage) and maintain day and night temperature at 26–28°C until daily inspection proves seedlings to be breaking the surface of the growth medium. If heating the propagation house to 26°C proves uneconomical or technically impossible, provide the extra heat to the germinating seed with bottom heat (i.e., heating pipes or heating cables under the table of the seeding trays). The higher the air temperature of the propagation room during germination the faster and more uniform the germination will be. However, seedlings grow fast at high temperatures, which makes the use of a high germination temperature risky because a delay of a few hours in removing the seed tray cover can result in excessive elongation of the seedlings and carbohydrate depletion. When seedlings have emerged, remove the seed tray covers, reduce the day and night air temperature to 22°C, and supply as much light as possible continuously. Maintain these conditions for the next several (5–7) days until seedlings grow enough that they can safely be handled, but not for too long because seedlings can get crowded, etiolate (stretch tall), and grow too slender.

Seedling transfer (transplanting)

If you have chosen to sow the seed directly into pots (preferably those 10 cm in diameter), you need not transfer the seedlings. If you sow the seed in trays, then you need to transfer the small seedlings from the trays to pots or rock-wool blocks. Note that seedlings transferred intact do

better than those transplanted or pricked out. Transferring the seedlings keeps their root systems intact; pulling the seedlings up from the growth medium and transplanting them into pots disturbs and severs many of the roots in the process. Take particular care in transferring cucumber seedlings because the cucumber root develops quickly. If the young root portions, which are most functional, are severed during transplanting, then the transplant can not absorb enough water after transplanting, usually experiences serious shock, and in many cases collapses.

Pots and soil

Choose from reusable plastic, clay, or paper pots, single-use pots of compressed peat, or peat-blocks. Good topsoil and peat mixes are used extensively as growth media after proper sterilization. A worldwide trend toward peat-based mixtures is replacing those based on soil, because soil of desirable specifications is difficult to obtain year after year.

Do not change frequently the substrate used for raising transplants because seedlings respond differently to different substrates. The experience gained over the years using one substrate may not be entirely transferable to other substrates.

Larger (10-cm) pots, although they appear to increase costs, allow growers to hold their plants longer in the propagation house, which is cheaper to heat than the entire greenhouse. Furthermore, longer propagation time results in greater use of artificial light whenever available. Finally, the use of large pots for transplant raising has frequently been associated with increased early yields. Pots can be used again the following season, but they should first be washed and soaked in a solution of bleach (10%) or any other approved disinfectant.

For transplants designated for soil, use topsoil to fill the pots. Avoid modifying recommended mixtures, as the results could be disastrous. Properly sterilized greenhouse soil that has good texture and structure is valuable as a growth medium for transplant raising. Heavy leaching following soil sterilization is highly recommended. This treatment removes excess salt, which can harm young seedlings and results in low levels of nutrients, especially nitrogen, in the growth medium. Low nutrient levels allow for better control of plant growth through the manipulation of liquid feeding.

For transplants designated for peat-bags, or other peat-based systems, use a proven commercial peat-mix, or prepare your own following the recommendations in Table 5 to fill the pots.

Immediately after transferring the seedlings into the pots, water them thoroughly to bring the growth medium to field capacity and to settle it around the roots. Subsequently apply fertilizer at low concentration with every irrigation; use a nutrient solution with an overall EC below 2000 $\mu S\ cm^{-1}$, as prescribed in Tables 6 and 7. Careful watering is needed during propagation. Keep the young plants well supplied with water without depleting the growth medium of its oxygen by overwatering. Because it is difficult to judge the moisture content of

growth media in plastic pots, pull out two or three plants regularly and keep the medium at the bottom of the pots moist but not too wet. Transplants raised in 10-cm pots require watering daily in good weather; in very bright weather, they may need more than one watering a day; in dull winter weather, watering as infrequently as once every 3 days may be enough. The use of smaller pots requires more-frequent watering.

Rock-wool blocks

When seedlings are ready, transfer them with their roots intact into 10-cm rock-wool blocks. These blocks come with cavities of various sizes, so when ordering rock-wool supplies, match the size of the individual cells in the multiblock units with the size of the cavity in the rock-wool propagation block. If you choose to seed directly into the propagation block, select the cavity size just big enough for the seed.

Place the rock-wool blocks, with seedlings, ideally on an ebb and flow system, and subirrigate them with the nutrient solutions prescribed in Tables 8 and 9. Use complete flooding, or watering from the top, from time to time to prevent excessive salt accumulation at the top of the rock-wool blocks that may burn the seedlings. However, where an ebb and flow system is not available, cover carefully leveled tables with a plastic film and place the blocks on the plastic. To improve on this system, provide a raised border around the perimeter of the table so that excess solution applied can be collected and saved. Perfect leveling of the tables is essential to facilitate complete drainage of the excess solution after every irrigation. Complete drainage prevents excessive variations in water and oxygen supplies to the transplants, which lead to unacceptable variation in the growth of the transplants.

Check carefully any excess fertilizer solution that is saved, and pasteurize it, adjust its nutrient content, before applying it again to the transplants. Implementing fertilizer recycling in transplant raising is more economically justifiable for the large operator. Placing the rock-wool blocks, with seedlings, on a layer of vermiculite (or any other water absorbent) reduces the frequency of required irrigation. However, it is not recommended because some roots grow outside the rock-wool blocks, which causes great delay and inconvenience at planting time.

Artificial light

Use artificial light first, as mentioned earlier, immediately after germination. Because you need only a relatively small installation at this stage, high light intensity is economically feasible. Both fluorescent (ideally in mixture with some incandescent) and high-pressure sodium (HPS) lamps are acceptable and are widely used to generate a minimum light intensity of 100 μmol s^{-1} m^{-2} (equivalent to 20 W m^{-2} or 8000 lux or 760 fc) in growing rooms. The fluorescent lamps produce slightly shorter plants with a deeper bluish green color than HPS lamps; but the latter are

the most economical to install and operate. During the first few days after the transfer, when the pots can be arranged close together, it is still economical to maintain a high light intensity (100 $\mu mol\ s^{-1}\ m^{-2}$) continuously. However, as the plants grow they are spaced progressively to avoid crowding and becoming spindly, which makes the use of high light intensity less and less cost effective. For the rest of the time, while the plants are in the propagation house, provide supplemental light (artificial light in addition to natural light) at a light intensity of about 50 $\mu mol\ s^{-1}\ m^{-2}$. Whenever cost is not a factor, provide continuously the highest light intensity available. This treatment results in shorter propagation time and heavier, stronger, sturdier transplants. There is no advantage in using low-intensity incandescent light on cucumber plants in midwinter to extend the daylight period.

Temperature control

Recommended temperatures for transplant raising, along with those mentioned earlier for seed germination and seed establishment, are summarized in Table 10.

Table 10 Recommended temperatures for raising cucumber transplants

Growth stage	Light conditions	Air temperature (°C)[a]		Root temperature (°C)[a]	
		Day	Night	Day	Night
Seed germination	Not critical	28	28	28	28
After germination	Maximum available continuous	24	22	26	26
After transplanting into pots	Good light conditions (summer or with artificial light)	23	21	24	24
	Poor light conditions (winter, with no artificial light)	22	20	24	22

[a] When continuous artificial light is supplied, the recommended daytime temperatures apply.

Carbon dioxide enrichment

During propagation, an atmosphere enriched with carbon dioxide at a nominal concentration of 1000 vpm ($\simeq$1000 ppm) increases plant vigor and early fruit production and may partly compensate for poor light

conditions. The beneficial effects of carbon dioxide enrichment are more evident when air temperatures are on the high side and are proportional to the duration of enrichment. Apply carbon dioxide during the day or any part of the night when artificial light is supplied. Because raising transplants occupies only a small area, it is economically feasible and highly advisable to use liquid carbon dioxide (carbon dioxide gas liquefied under pressure) because of its guaranteed purity and amenity to accurate concentration control. Liquid carbon dioxide is also preferred because burning natural gas or propane to generate carbon dioxide increases the risk of plant injury from gaseous pollutants.

Grafting

Grafting is a useful technique when soil sterilization is not available or when certain diseases, e.g., black root rot, cannot always be controlled effectively by soil steaming. Cucumber seedlings of popular hybrids are usually grafted onto resistant rootstocks, such as *Cucurbita ficifolia*. The seed of *C. ficifolia* is normally sown a few (5–6) days later than the cucumber hybrid and may have to be chitted (a small part of the seed coat is cut away) and pregerminated because of its hard seed coat. Figure 7 shows various grafting methods suitable for cucumbers.

All types of grafting require a sharp knife and a clean working surface; a razor blade or scalpel are ideal tools. Avoid contaminating cuts with soil. Type A grafting (Fig. 7A) is the fastest but is associated with the most check in the growth of the transplant. Type B grafting (Fig. 7B) is also fast and results in a stable grafting union, but some check in the growth of the transplants can be found. Type C grafting (Fig. 7C) is the slowest but is usually associated with the greatest success in grafting.

Grafting can be helpful in saving the cost of soil sterilization and in allowing the cropping of cultivars that are productive but devoid of adequate disease resistance. However, it poses its own problems. The graft union becomes an obstacle to water and nutrients moving from the roots to the top of the plant and to photoassimilates moving from the top of the plant to the root. Grafting is therefore a potential limiting factor in maximizing yield.

Grafting also requires skilled labor, which is either expensive or not readily available. The difference in vigor between scion and rootstock can result in significant differences in stem diameter (a minimum diameter of 5 mm is desirable), which slows down the speed of grafting and reduces the success rate.

Finally, repeated handling of plants at grafting may help spread diseases. It is therefore extremely important to clean the knife regularly and to wash the hands frequently with milk during grafting. Make every effort to start with clean seed.

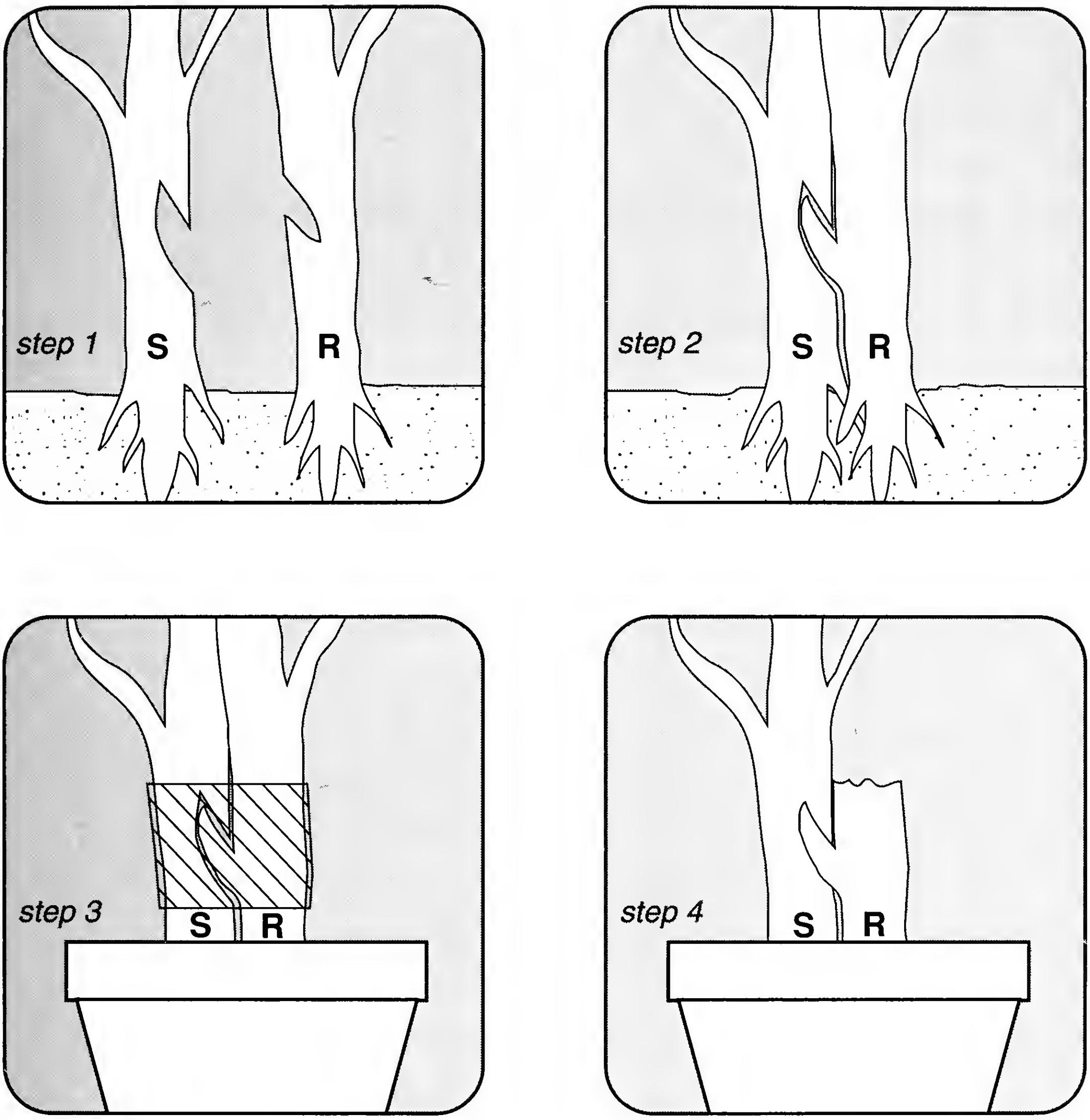

Fig. 7A Bare-rooted plants, bench graft.

Step 1
Select a rootstock (R) and a scion (S) plant of similar size. Make an upward cut in the stem of one and a downward cut in the stem of the other.

Step 2
Join the two stems, which are then held together by the flaps of tissue.

Step 3
Bind both plants together with adhesive tape, and plant them in a pot with the graft union well above soil level.

Step 4
Remove the top of the rootstock and the adhesive tape when the graft union has healed.

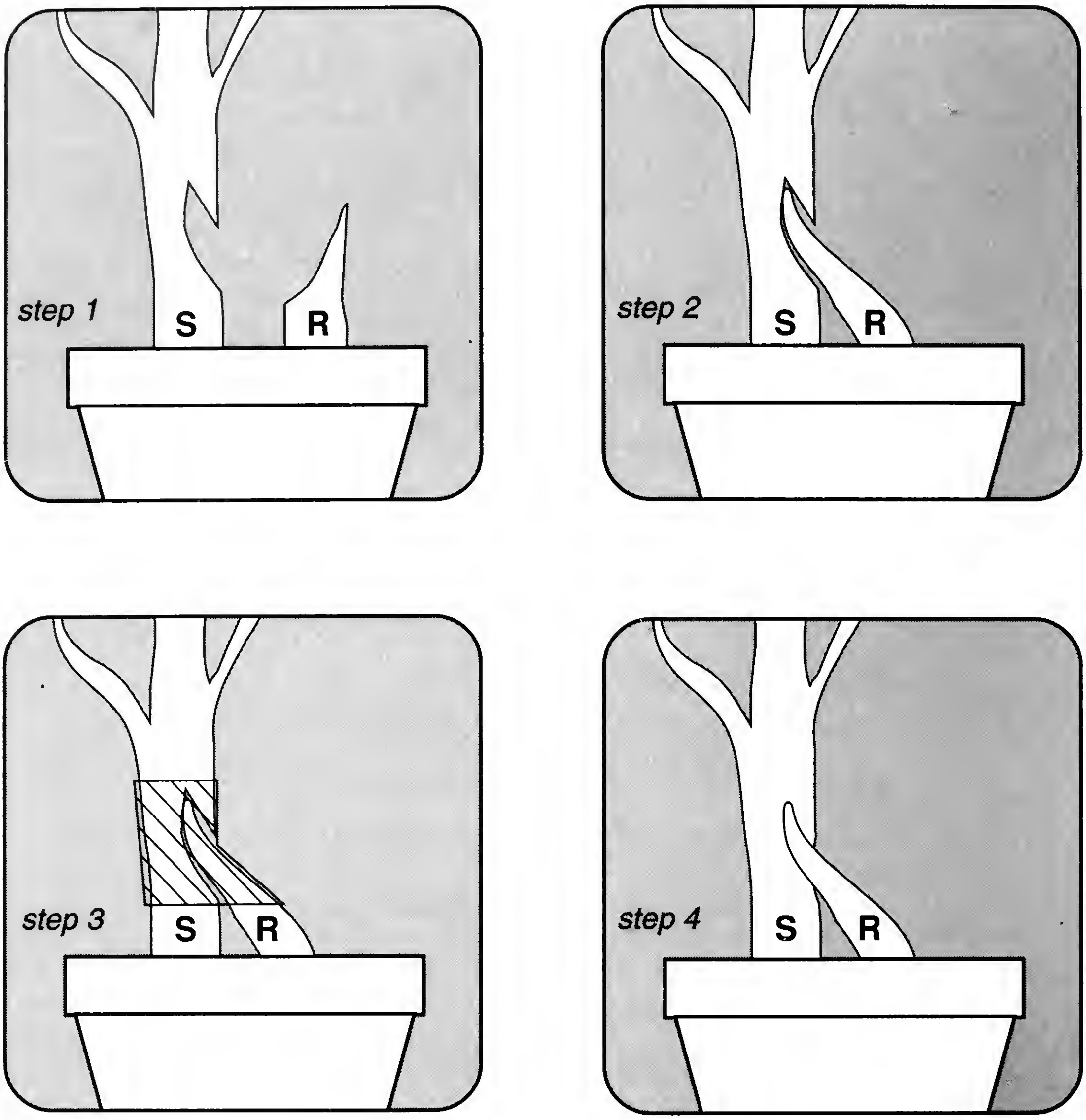

Fig. 7B Rootstock and scion-plants grown in same pot; immediate detopping of the rootstock.

Step 1
Make an upward cut in the scion (S) and remove the rootstock (R) top with a diagonal cut.

Step 2
Place the top of the rootstock stem into the cut of the scion stem.

Step 3
Remove obstructing leaves and bind the two plants together with adhesive tape.

Step 4
Remove adhesive tape when the graft union has healed.

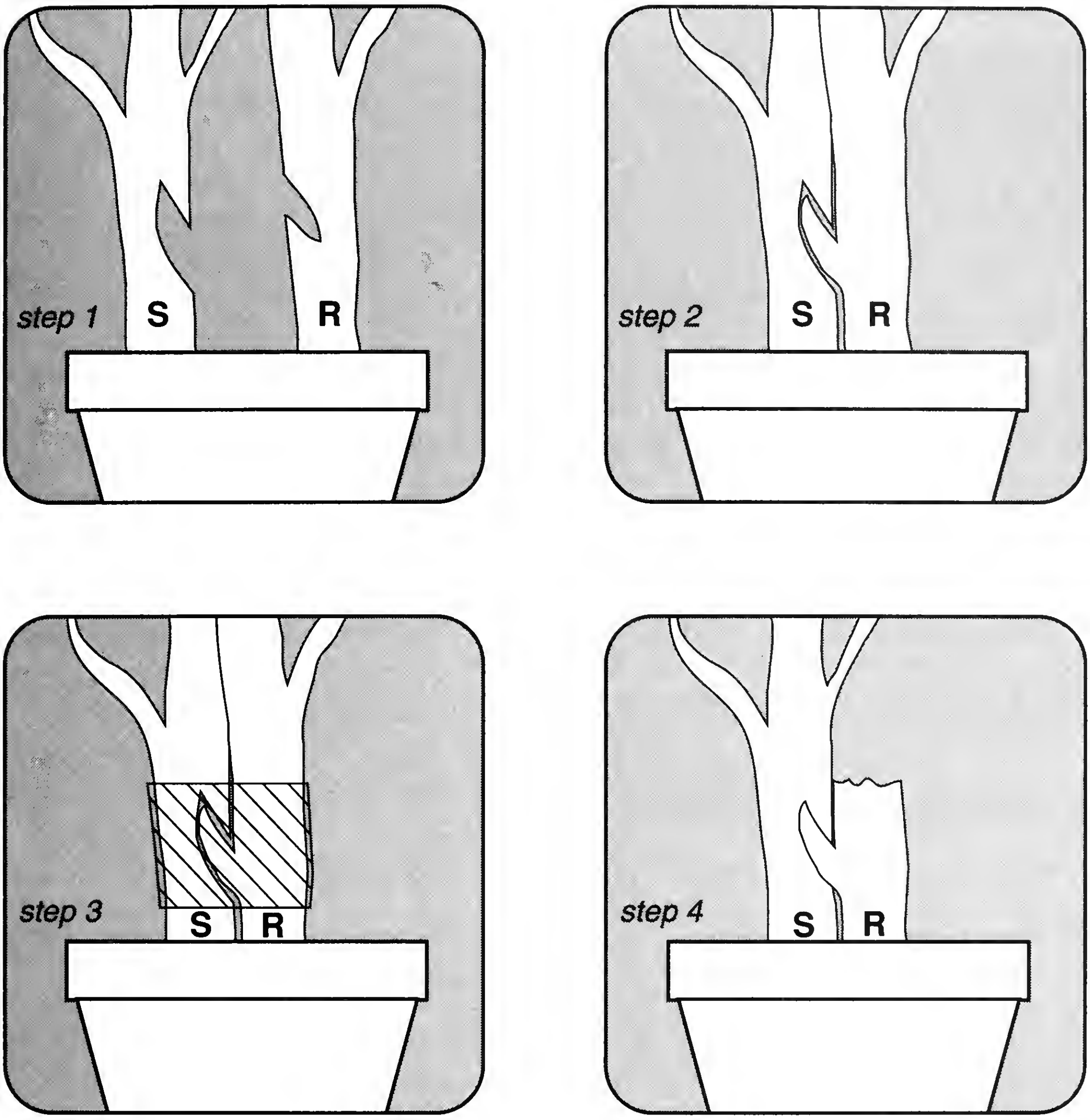

Fig. 7C Rootstock and scion plants grown together in same pot; delayed detopping of the rootstock.

Step 1
Plant scion (S) and rootstock (R) 10 mm apart in the same pot and grow them until they are ready for grafting. Make an upward cut in the scion and a downward cut in the rootstock.

Step 2
Join the two stems, which are then held together by the flaps of tissue.

Step 3
Bind both plants together with adhesive tape.

Step 4
Remove the top of the rootstock and the adhesive tape when the graft union has healed.

Plant spacing

The optimum space per plant is generally agreed to be 0.70–0.80 m^2. Ideally, use the same spacing between rows of plants as between plants in the row. However, to facilitate working among the plants, use double rows for planting. Place the first two rows 80–120 cm apart and allow 140–200 cm for a walking path before repeating two more rows spaced at 80–120 cm apart; repeat the process as necessary. The location of posts, heating pipes, and other physical limitations of the greenhouse structure may influence plant density, especially row spacing.

Factors such as cultivar, season, and growth medium influence plant spacing. Space the plants in the rows at 45–60 cm. Space farther apart cultivars that are vigorous (large leaves). Late spring and early fall crops enjoy favorable light conditions and therefore, plant spacing can be closer. Also, crops planted in rock wool or finely textured soils (high clay content) tend to be of low vigor (small leaves); therefore spacing must be close. Actual-row and within-row plant spacing depends on the training system chosen. Although it is important to use the space in the greenhouse as efficiently as possible, excessive crowding usually results in small fruit and outbreaks of leaf disease.

Pruning and training

General principles

Pruning involves making a series of decisions based upon the basic concepts of plant growth. Growth is accomplished when water and nutrients absorbed by the plant are transported to the leaves and combine with carbohydrates (formed through photosynthesis) to produce various plant foods. Any reduction in leaf area therefore reduces the amount of plant food manufactured, which in turn reduces growth. Although pruning usually causes the remaining shoots to increase their length and their leaf area, especially near the cuts, the total plant size and weight is greatest without pruning. Thus, pruning is a dwarfing process.

The main reasons for pruning plants are as follows:

- to help recovery from injury to the roots
- to remove dead or injured growth
- to remove or restrict unwanted growth
- to encourage or train growth where it is desired
- to rejuvenate old plants
- to promote flower and fruit production
- to facilitate light penetration throughout the leaf canopy for more efficient use of light
- to expose fruit to light when beneficial.

Pruning and training greenhouse cucumber plants create conditions for maximum yield production of high-quality fruit by establishing and maintaining

- optimum fruit load

- complete leaf coverage (i.e., no light reaching the ground)
- uniform exposure of all foliage (for efficient light absorption).

Although training is, for practical reasons, uniform for all plants, pruning offers the opportunity to adjust the fruit load of each individual plant according to its vegetative vigor. Maintaining the proper balance in each plant is essential for maximum productivity and best fruit quality.

Under a heavy fruit load, many fruits do not develop properly (fruit is malformed, curved, short, or of poor color). When eventually the load becomes excessive, abortion prevents any further development of fruit. Avoid overloading the plants by removing excess fruit, as early as possible, starting with curved and pointed fruit. Allow only one fruit per axil.

Because fruit will not develop without a continuous production of leaf axils, you may need to resort to drastic pruning to stimulate growth. In this case, it is more practical and equally effective, to remove whole laterals than to trim back the tips of all laterals.

Maintaining the proper fruit load prevents overall plant stress and wastage of photosynthates and ensures steady fruit production throughout the season.

When vegetative growth is strong, fruit production suffers at the expense of excessive leaf development, which fuels an already overvegetated plant. Also, excessive vegetative growth results in extensive shading of the fruit causing it to be of poor quality (i.e., slow growth, pale color, and possibly excessively ribbed).

Pruning systems

Always prune cucumber plants to a single stem and support them by plastic twine. Place one end of the twine under the pot at planting time; attach the other end to an overhead wire supported 1.8–2.5 m above the plant row. As a plant grows, it winds around the twine. Remove side shoots or fruit, or both, according to the pruning and training system, at least every week. As the plant becomes larger and carries a lot of fruit, use twist ties or plastic snap-on clips to attach it to the twine. Avoid removing the lower leaves as long as they are healthy and productive unless necessary for improving air circulation. When the overhead wires are low (less than 2 m), the early removal of the lower foliage may be detrimental to yield; keep a minimum of 1.5 m of leaf-bearing stem. The dilemma of adequate leaf area versus sufficient air circulation is avoided in modern (tall) greenhouses by fixing the support wires much higher than 2 m.

The main pruning systems practiced on greenhouse cucumbers are the original umbrella system and the modified umbrella system and their variants. A short description follows.

Original umbrella system

To prune a plant according to the original umbrella system (Fig. 8a), follow these step-by-step instructions.

Step 1
When the main stem reaches the horizontal wire (i.e., 2.0–2.5 m high), pinch out the growing point allowing an extra two or three leaves above the wire. Use a small piece of a string, or a plastic clip, to tie the main stem to the wire; the extra two or three leaves above the point of attachment will help prevent the plant, when fully loaded with fruit, from slipping down.

Step 2
Remove all fruit and laterals from the lowest 60 cm of the main stem.

Step 3
Remove all fruit from the next 60 cm of the main stem but allow the laterals to grow to their first leaf and then pinch them; allow one fruit to develop on each lateral.

Step 4
Allow one fruit and a lateral to grow from each leaf axil of the rest of the main stem; pinch the laterals after the second leaf and allow two fruit on each lateral (i.e., one in each leaf axil of the lateral).

Step 5
Allow the two strongest laterals from the top of the plant to grow over the horizontal wire and then to hang down along the main stem; pinch these primary laterals when they grow one-half to two-thirds of their way down to the ground.

Step 6
Allow a secondary lateral from the axil of each leaf on the primary lateral to develop, pinch each secondary lateral after the second leaf and allow two fruit to develop on each secondary lateral.

Step 7
Remove any lateral if its fruit touches the ground.

Variations In the first variation of the original umbrella pruning system (Fig. 8b), allow the main stem to grow along the horizontal wire (twisting it around the wire) and let it continue growing downwards as a "primary lateral." Then train a sideshoot from a leaf axil at the top of the plant as a second "primary lateral" on the other side of the main stem.

In a second variation of the original umbrella pruning system (Fig. 8c), train the main stem along the horizontal wire until it reaches the next plant and then pinch its head. Then allow two sideshoots from leaf axils on the segment of the main stem trained along the horizontal wire to grow downwards in the usual way.

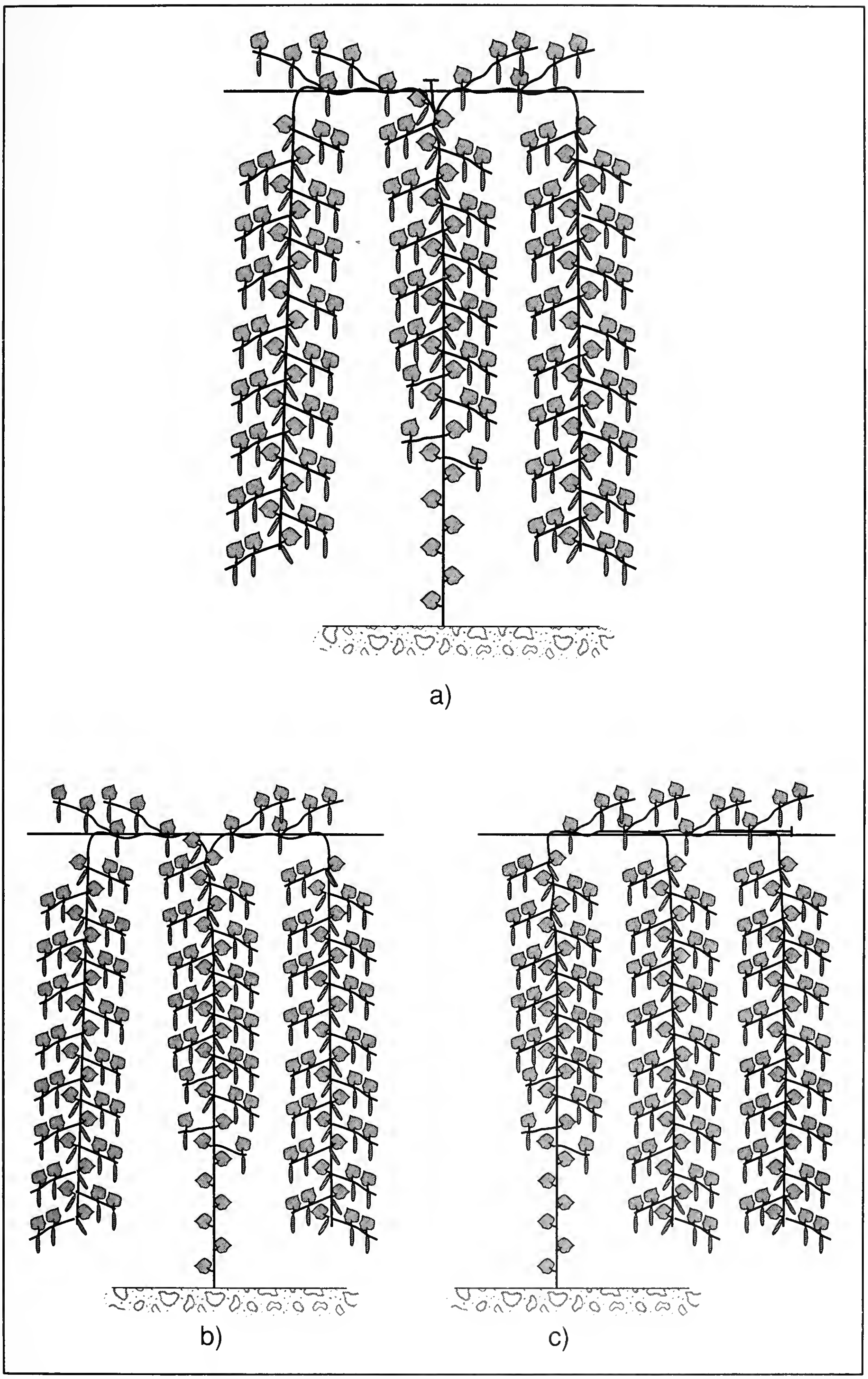

Fig. 8 Original umbrella pruning system: *a* standard form; *b* first variation; *c* second variation.

Modified umbrella system

To prune a plant according to the modified umbrella (stem fruit) system (Fig. 9a), follow the step-by-step instructions.

Step 1
When the main stem reaches the horizontal wire (2.0–2.5 m high), pinch out the growing point allowing an extra two or three leaves above the wire. Use a small piece of a string, or a plastic clip, to tie the main stem to the wire. The extra two or three leaves above the point of attachment help prevent the plant, when fully loaded with fruit, from slipping down.

Step 2
Remove all fruit and laterals from the lowest 0.8–1.0 m of the main stem.

Step 3
Continue removing all laterals, but allow one fruit to develop from each leaf axil of the rest of the main stem.

Step 4
Allow two laterals from the top of the plant to grow over the wire and then to grow down along the main stem (one on each side). Pinch the primary laterals before any fruit developing on them could touch the ground.

Step 5
Remove all sideshoots from the primary laterals and allow only one fruit to develop at each leaf axil of the lateral.

Step 6
When the primary laterals get old and unproductive, allow new sideshoots to develop at the top of the plant and repeat the cycle of steps 4 and 5. Before allowing new laterals to grow downwards, make sure they first grow over the horizontal wire for better support and light exposure.

Variations In a first variation to the modified umbrella (stem fruit) system (Fig. 9b), allow the main stem to grow along the horizontal wire (twisting it around the wire) and then let it continue growing downwards as a "primary lateral." Then train a side-shoot from a leaf axil at the top of the plant as a second "primary lateral" on the other side of the main stem.

In a second variation (Fig. 9c), train the main stem along the horizontal wire until it reaches the next plant and then pinch its head; then allow two sideshoots from a leaf axil on the segment of the main stem trained along the horizontal wire to grow downwards in the usual way.

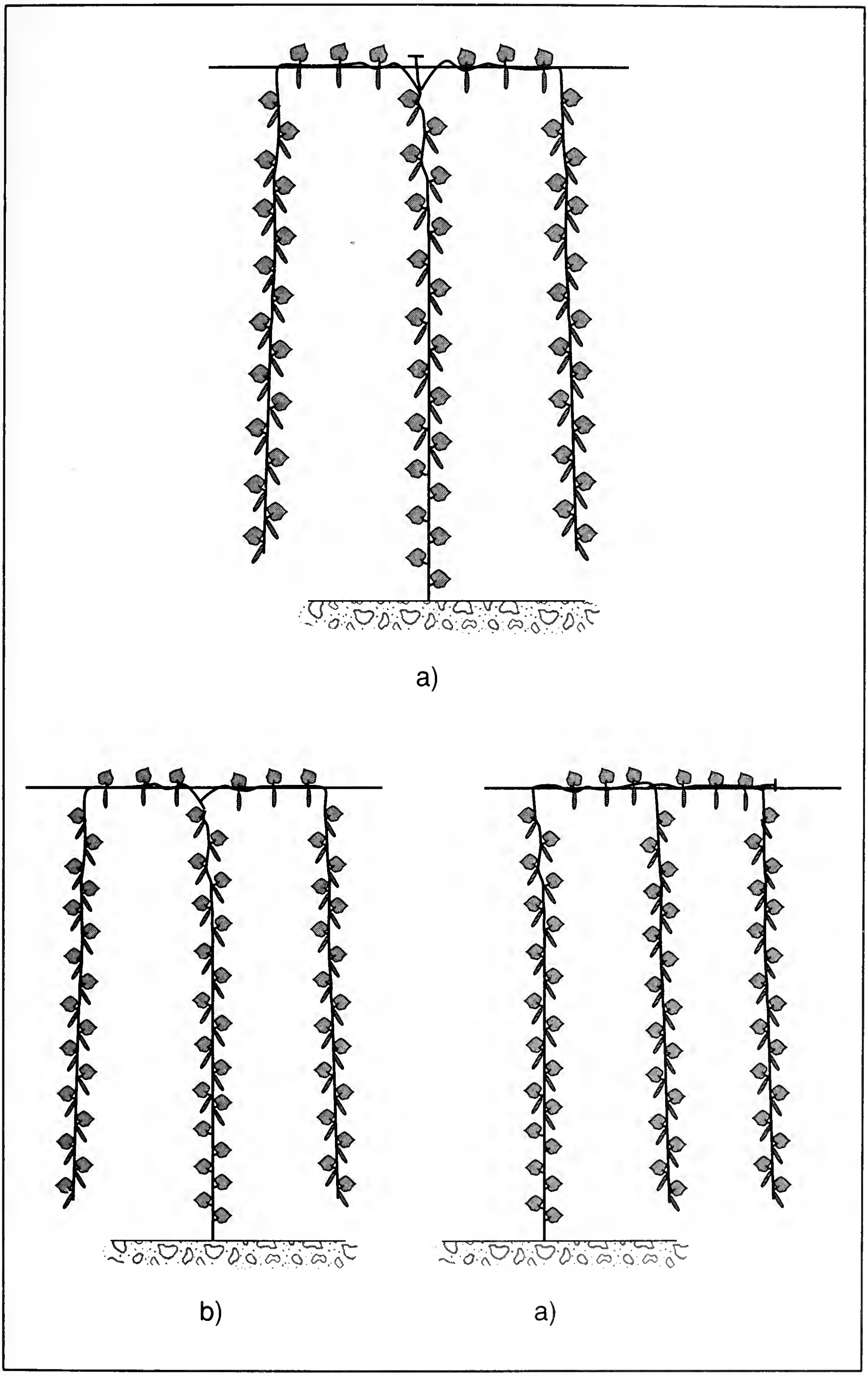

Fig. 9 Modified umbrella (stem fruit) pruning system: *a* standard form; *b* first variation; *c* second variation.

Training systems

Modern cucumber cultivars grown as greenhouse crops retain the characteristic weak stem of their wild ancestors, so they require support when grown with a single vertical stem.

The main cucumber training systems are the canopy system, the vertical cordon, the inclined cordon (V-cordon), and the Guernsey arch. A short description of each follows.

Canopy system

Set plants to be trained according to the canopy system (Fig. 10) in double rows 120-140 cm apart, with walking paths 180–200 cm wide separating the double rows. In-row spacing can vary between 40–60 cm depending on desirable planting density. Position horizontal support wires directly over the rows of plants, at a height of 2.0–2.5 m (depending on greenhouse structure and convenience, the higher the better). At the same height, extend a variable number of horizontal wires in the same direction as the rows, over the walking paths, to provide a convenient support and to give form to the canopy.

Train plants initially vertically along and around the support (plastic) strings. When they reach the horizontal wires, train them horizontally over and across the walking paths.

Terminate the main stem, depending on in-row plant spacing, either half way across the walking path or after it runs the full width of the walking path. Prune these plants according to the modified umbrella system. However, train the primary laterals, and any subsequent growth, over the horizontal wires, rather than allowing them to grow vertically, and allow only the fruit to hang down. The constant need for training new growth over the wire to maintain the canopy, especially during the heavy harvest period, is a serious disadvantage of this training system. The advantages are a smaller number of rows (i.e., substantial savings in growth media and labor) and a potential for straight (high-quality) fruit.

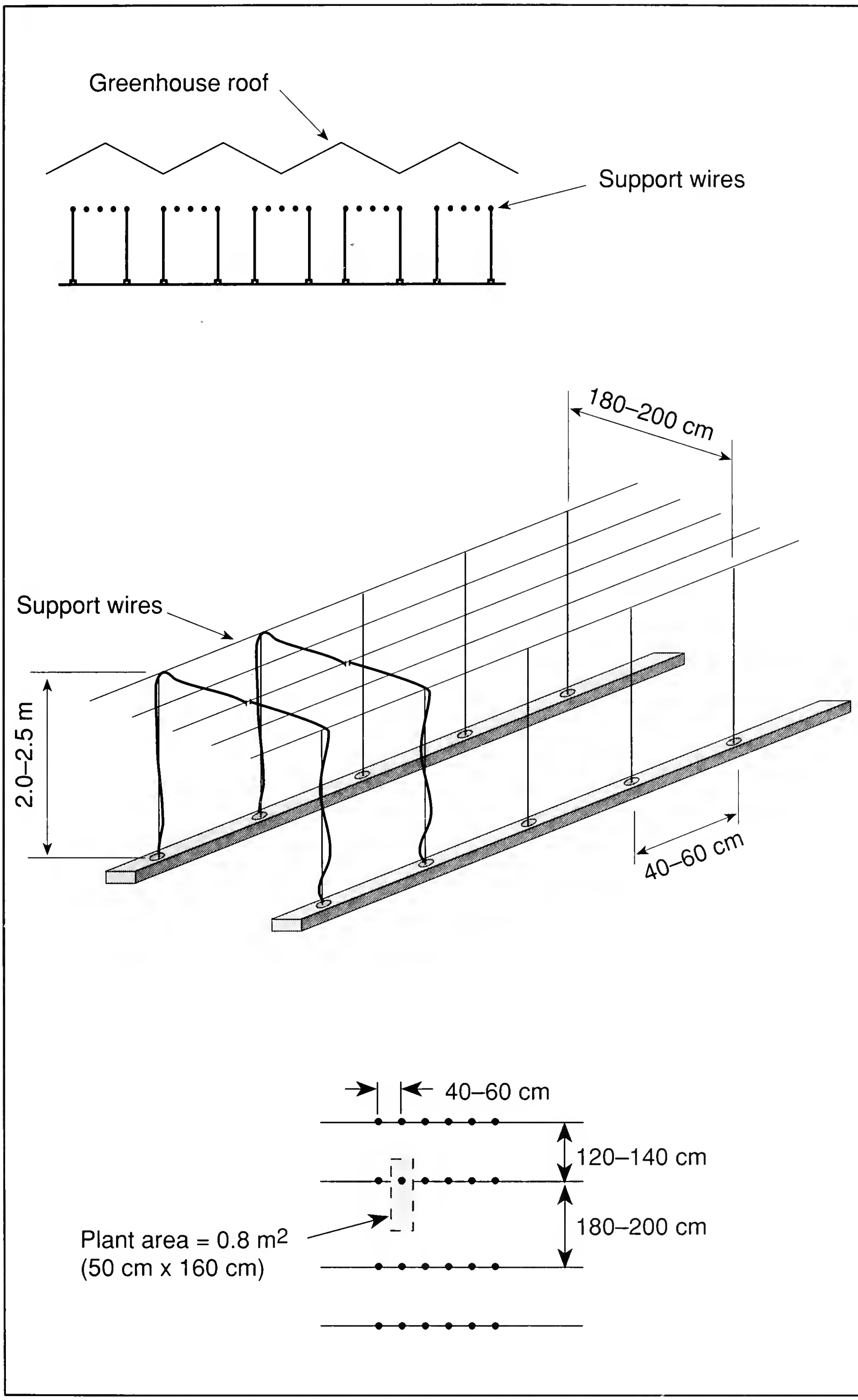

Fig. 10 The canopy training system.

Vertical cordon

Set plants to be trained according to the vertical cordon system (Fig. 11) in double rows 100–120 cm apart with walking paths, 140–160 cm wide, separating the double rows. In-row spacing can vary between 50–70 cm depending on desirable planting density. Position horizontal support wires directly over the rows of plants, at a height of 2.0–2.5 m (depending on greenhouse structure and convenience, the higher the better). Initially train each plant vertically along and around the support (plastic) string and then along and around the horizontal wire until it reaches the next plant. Prune these plants according to the modified umbrella system, or, under conditions of exceptionally good light and low cost for trained labor, according to the original umbrella system. The minimal plant support infrastructure needed and the system's simplicity make it the most attractive and popular training system. However, research and practical experience in most parts of Canada indicate that this system may not always be the best for maximizing light absorption or the most productive. The vertical cordon training system has a definite advantage in producing high early yield, but its actual effect on the final yield is still debated.

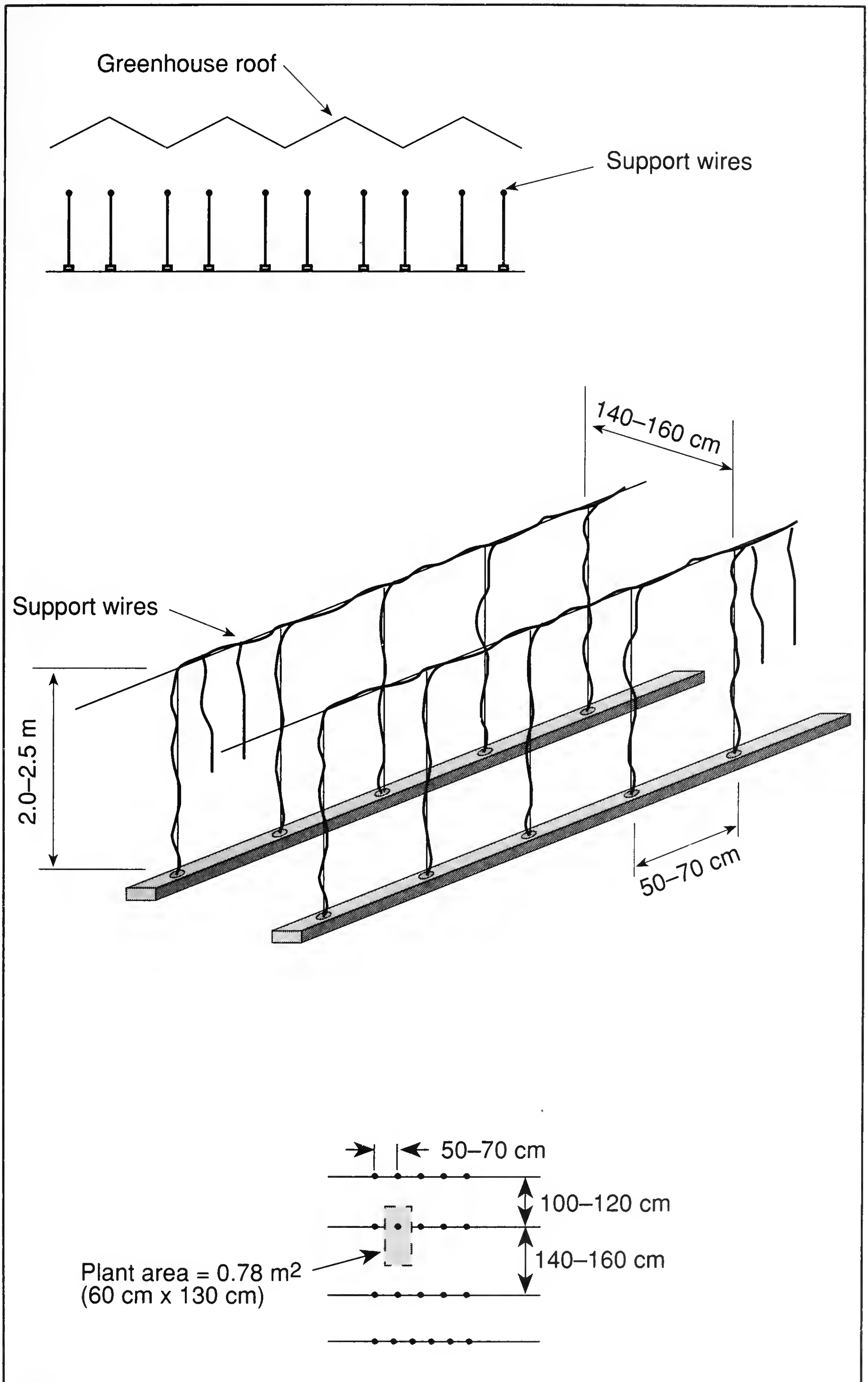

Fig. 11 The vertical cordon training system.

Inclined cordon (V-cordon, V-training) system

Set plants to be trained according to the inclined cordon system (Fig. 12) in double rows, 140–160 cm apart with walking paths, 160–180 cm wide, separating the double rows. In-row spacing can vary between 40–60 cm depending on desirable planting density. Position two horizontal wires, 60–80 cm apart, over each row of plants at a height of 2.0–2.5 m (depending on greenhouse structure and convenience, the higher the better). Initially train plants on an angle, along and around strings that are stretched alternatively to the overhead wires, and later along and around the horizontal wire (for twice the in-row spacing) until they reach the next plant inclined in the same direction. As a result, plants incline away from the row of planting, guided by the offset support wires above, and form a canopy V-shaped in cross section. As with the canopy training system and because of the reduced number of rows, there are substantial savings in growth media and labor. Besides, because of the alternate inclination of the main stems,

- light can penetrate better down the plant canopy and be distributed more uniformly over the leaf area
- fruit hangs away from the main stem becoming straight and of better color (quality)
- stem to stem distance effectively doubles that of the actual plant spacing, so plant pruning and training become more convenient.

Prune plants trained according to the inclined cordon system according to the modified umbrella system. Under conditions of exceptionally good light and low cost of trained labor, they are trained according to the original umbrella system.

Variations In one possible variation of the inclined cordon system, use two rows of growth medium at a small distance from each other (e.g., 20–40 cm) instead of one. This approach is preferable when the growth medium allotment per plant must be increased, or, when the slope of the main stems must be reduced.

In a second possible variation of the inclined cordon system, install an extra two or three horizontal wires. These wires provide extra support to the main stem and prevent plants from distorting the ideal V-shape, sagging into the pathway, and obstructing traffic in the walking paths. They also prevent excessive stem and fruit breakage by the harvesting crews. The inclined cordon system, especially its variation with the extra horizontal wires, has become popular in some European countries, where it is believed to have a high yield potential.

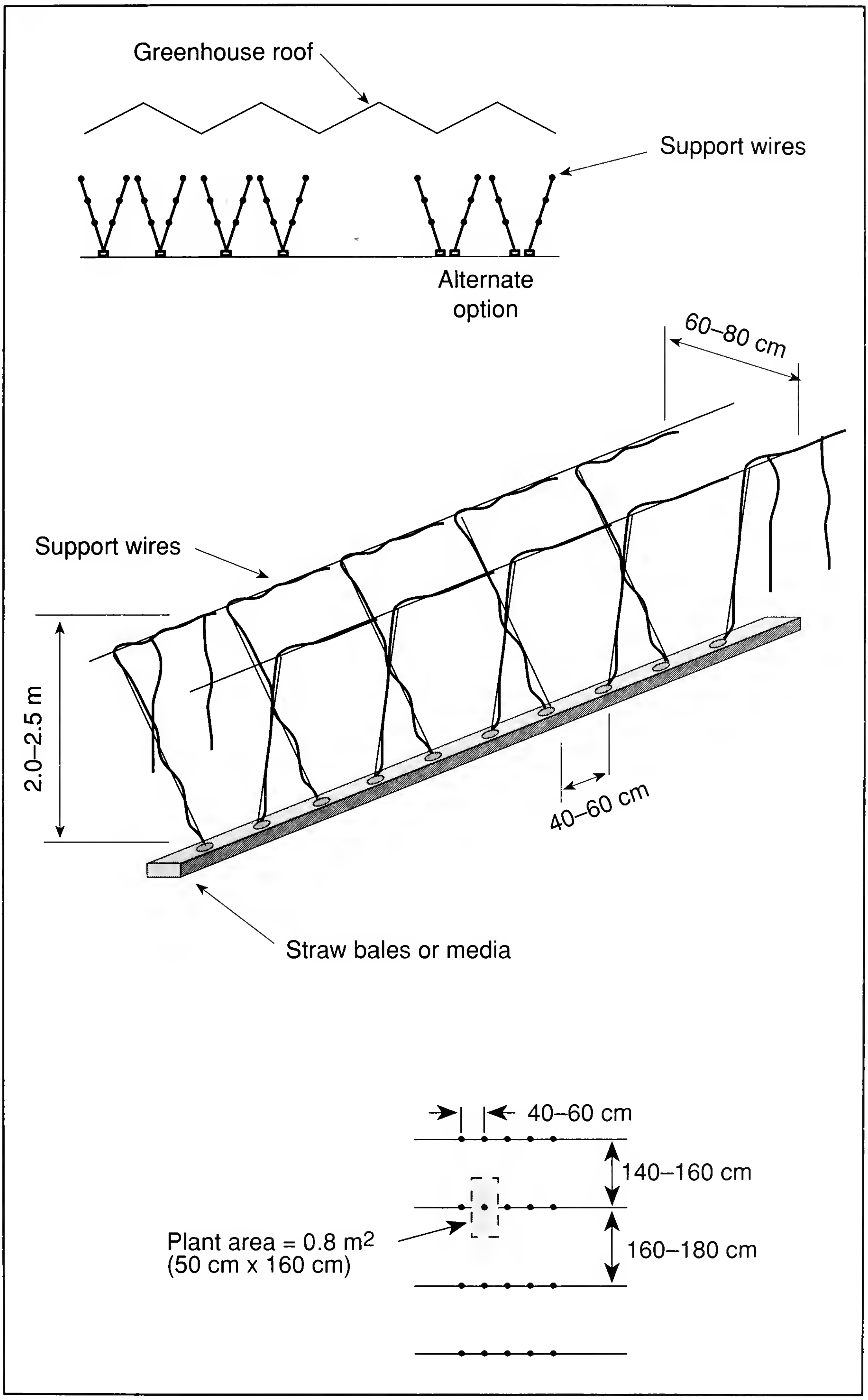

Fig. 12 The inclined cordon, V-cordon, or V-training system.

Guernsey arch

This training system (Fig. 13), as the name indicates, originated on Guernsey (one of the Channel Islands) where it was popular for many years. However, this training system is rarely used today since the demise of the greenhouse vegetable industry in those islands, and because it requires considerable quality labor to establish and maintain the arch. The system is described briefly here primarily for historical reasons.

Set plants to be trained according to this system in single rows spaced 3.5–4.5 m apart. Traditionally one arch was practiced in each narrow greenhouse or two arches in wide-span (e.g., 30-ft) greenhouses. Keep in-row spacing close (e.g., 20–30 cm), unless two parallel rows of plants are grown at a short distance from each other to facilitate a larger allotment of growth medium per plant (in that case, provide in-row spacing of the usual 40–60 cm). The arch, a series of inverted Vs, normally has a width at the base of 3.5–4.5 m, a height at the apex of about 2.2–2.5 m, and a height of about 70–80 cm at the sides. The skeleton of the arch is provided by an elaborate system of horizontal wires extended over wooden (or metal) supports having the shape of an inverted V or U. Initially allow the main stems to grow vertically in front of the first couple of wires. In this way the lower part of the plant can allow for some movement at a later time without the main stem breaking or the plant pulling out of the growth medium. Subsequently, train the main stems over the remaining horizontal wires, tie with string or plastic clips, and pinch when they reach the apex of the arch. Train the primary laterals developing out of each leaf axil of the main stem at right angles to the main stem. Tie them in the usual manner on the horizontal wires, and stop them after the second leaf. Train and tie secondary laterals developing out of each leaf axil of the primary laterals at right angles to the primary laterals (and support wires). Stop them after one or two leaves depending on plant vigor, fruit load, and coverage of the arch with foliage. During this tying-in period, which usually takes 4–5 weeks from planting, remove all fruit developing in the leaf axils of the main stem at an early stage. The first fruit to be harvested develops from the leaf axils of the primary laterals. Because stems and foliage now cover the arch, no further tying-in is required. Now simply trim (i.e., stop sideshoots, remove dead or aging leaves and stems, and remove unmarketable fruit) and pull fruit through the wires to hang inside the arch.

Developing the arch requires much labor and skill, but maintaining the canopy is relatively easy. Definite advantages are the high quality of fruit, ease of harvest, economy in growth medium because of the small number of rows, and the potential for high yield over an extended cropping season. Several variations of the Guernsey arch exist but their description is beyond the scope of this publication.

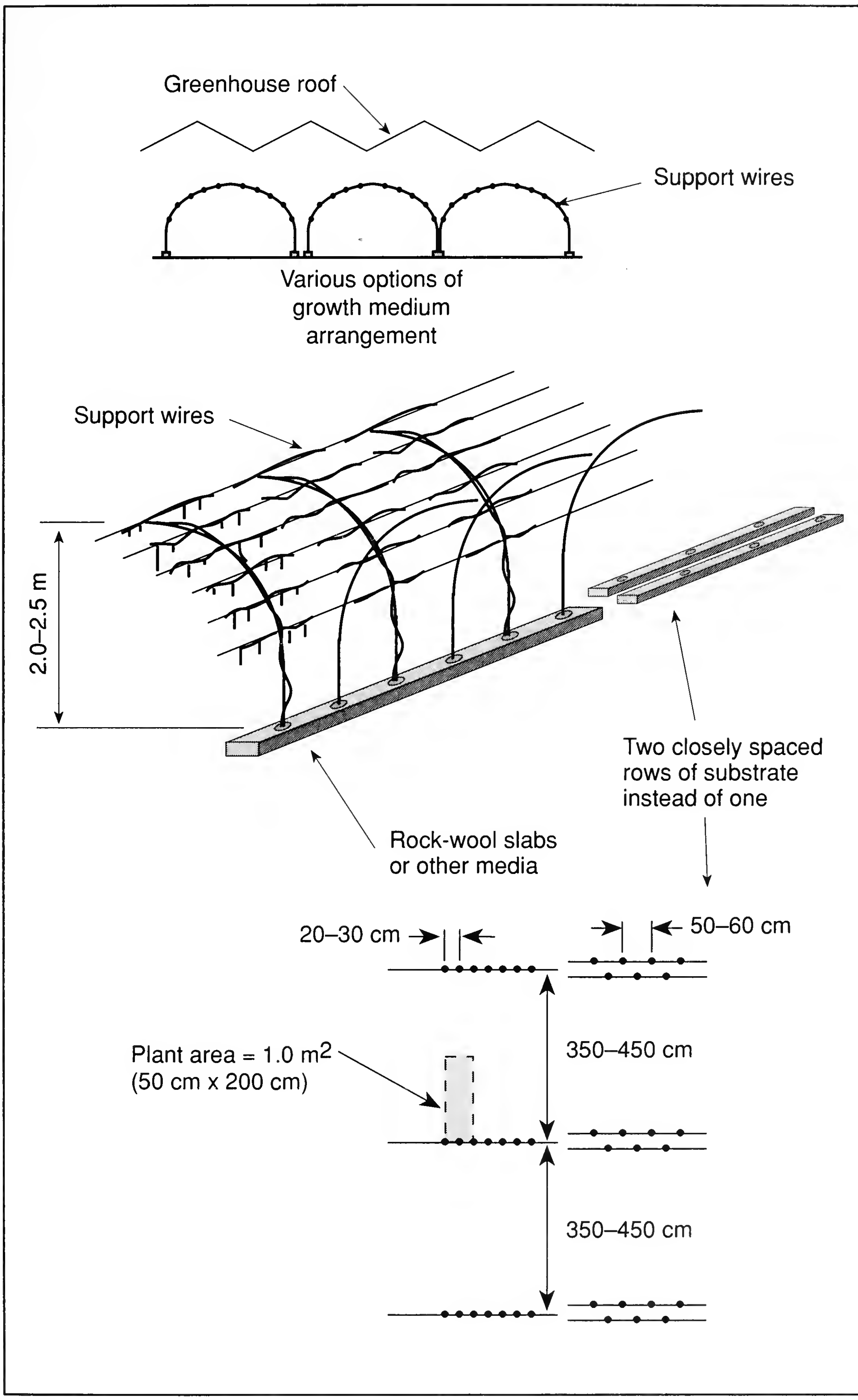

Fig. 13 The Guernsey arch training system.

Choosing a training and pruning system

Although the training and pruning systems described appear very different, all aim to produce an optimum foliage coverage and distribution and an optimum balance between vegetative growth (plant vigor) and fruit load. Choosing a training system is difficult; research results are limited because of the large size of the trials needed and because many factors, including availability and cost of trained labor, must be taken into account.

In general, the vertical cordon and canopy systems require little labor and, especially during the busy harvesting season, are easiest to apply. They also require only simple support systems and little technical skill in training.

The inclined systems (inclined cordon and Guernsey arch) require definite technical skill in training and elaborate support systems (especially in the case of the Guernsey arch). However, the extra time needed for applying these training systems is mostly invested during the early part of the season. Much of that investment in time is recouped later by the shorter time spent in harvesting the fruit, which is more exposed and accessible. Because of the way the fruit hangs out in the open, fruit quality is high.

With regards to the pruning systems, the modified umbrella system and its variants require little technical skill and in most cases produce satisfactory results. The original umbrella system may be preferable when light conditions are exceptionally good (late spring, summer, and early fall) and a short crop is planned.

Fruit thinning

Overbearing can sometimes be a problem. To prevent the plants becoming exhausted and to improve fruit size, control the number of the fruit per plant through selective fruit thinning. This technique is powerful, so use it with great caution. The optimum number of fruits per plant varies with the cultivar and, even more, with the growing conditions. Although, limiting the number of fruits per plant invariably results in premium-priced large fruit, growers risk underestimating the crop's potential or failing to forecast good weather. They may decide to remove too many fruits and thus unnecessarily limit production. Fruit thinning is undoubtedly most useful in the hands of experienced growers who can use it to maximize their financial returns. Fruit to be pruned must be removed as soon as it can be handled, before it grows too large.

Harvesting and storage

After all the effort and money invested in production, it is essential that fruit be handled well at harvesting and during transportation to the market.

Most growers pick twice and even three times a week in hot weather. Pick fruit carefully and place them in soft plastic, or better, padded containers to avoid bruising and damage. The size of the fruit at harvest is important. Harvesting underdeveloped fruit loses revenue because larger fruit sells easier and at a better price. However, fruit left on the plants for too long not only prevents new cucumbers from developing but also has a short shelf life expectancy when harvested. Make every effort to minimize losses in fruit quality during harvest and transit. Overfilling the crate or stacking the produce too high may damage the bottom layer.

Harvest fruit in the early morning, while the day is still cool. Move produce immediately out of direct sunlight and into cool, shaded, ventilated areas so that fruit temperature does not rise. Wrap each fruit individually with thin plastic film to conserve its water and extend its shelf life.

Use a covered vehicle to transport the produce to the packing shed, thus protecting the fruit from direct sunlight and exposure to the drying effect of air. Do not park a loaded truck in direct sunlight for any length of time. During transportation, minimize heat gain and place produce in cold storage (12°C) as soon as it arrives at its destination. Fruit stored under ideal conditions (i.e., 10–13°C and 90–95% RH) has a life expectancy of 10–14 days. Stacking the crates too high or too tight prevents the crates in the middle from cooling down adequately when the product is stored in a cooler.

Packing and storing produce in the same place as active ethylene producers, such as apples, accelerates ripening and results in yellowing of the fruit. Avoid storing and shipping tomatoes and cucumbers together. After removing fruit from cold storage, do not allow water to condense on it, especially if fruit is not shrink-wrapped. Prevent condensation by keeping the environment dry through ventilation or by raising the storage temperature gradually before the fruit is removed. **After harvest, the quality of cucumbers can only be preserved, not increased.**


a
b
c
d
e
210/18N
GLASS
f
g
h
i

◀ **Plate I Effect of the day and night air temperature (DAT and NAT, respectively) on the growth and development of greenhouse seedless cucumbers; Spring 1993, nine mini greenhouse complex, Harrow Research Station.**

a **Cover: glass (DAT=18°C, NAT=16°C);**
b **Cover: double polyethylene (DAT=18°C, NAT=18°C);**
c **Cover: acrylic (DAT=18°C, NAT=20°C);**
d **Cover: acrylic (DAT=21°C, NAT=16°C);**
e **Cover: glass (DAT=21°C, NAT=18°C);**
f **Cover: double polyethylene (DAT=21°C, NAT=20°C);**
g **Cover: double polyethylene (DAT=24°C, NAT=16°C);**
h **Cover: acrylic (DAT=24°C, NAT=18°C);**
i **Cover: glass (DAT=24°C, NAT=20°C).**

Plate II The Harrow Fertigation Manager® (HFM®), a computerized multifertilizer injection system (U.S. Patent #5 184 420) for the precise application of water and nutrients according to the changing needs of various crops. (Harrow Fertigation Manager® and HFM® are registered trade marks of Labbate Climate Control Systems Inc., 509 Hwy #77, R.R. #5, Leamington, Ont.)

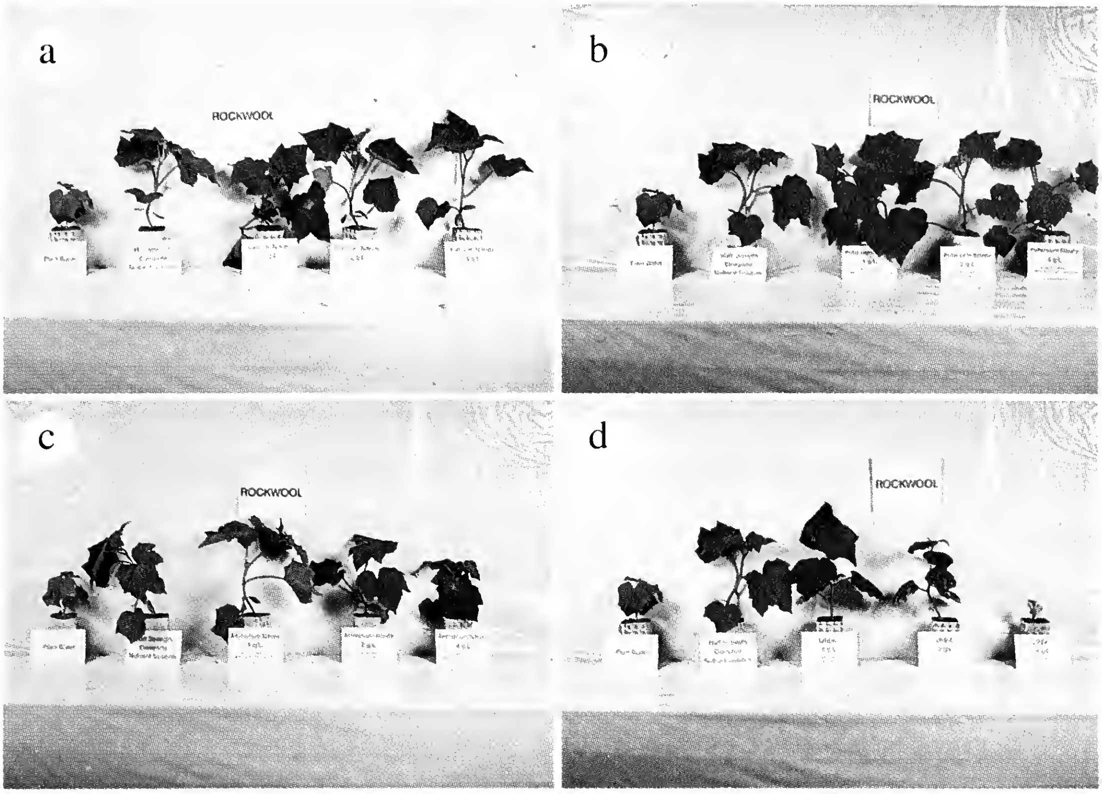

Plate III Effect of the form (nitrate vs. ammonium) and rate of nitrogen on the growth of greenhouse seedless cucumber transplants in rock wool.

Rates of fertilizer application (*from left to right*):

1. **Plain water (no fertilizer)**
2. **Half strength of complete nutrient solution (HSCNS) (see Table 9, approx. EC = 1000 $\mu S\ cm^{-1}$)**
3. **HSCNS + 1 g L^{-1} of additional nitrogen source**
4. **HSCNS + 2 g L^{-1} of additional nitrogen source**
5. **HSCNS + 4 g L^{-1} of additional nitrogen source**

a **Effect of calcium nitrate (100% nitrate);**
b **Effect of potassium nitrate (100% nitrate);**
c **Effect of ammonium nitrate (50% nitrate, 50% ammonium);**
d **Effect of urea (100% ammonium).**

Plate IV Cropping of greenhouse seedless cucumbers in soil and soilless media:

a **conventional cropping in soil;**
b **cropping in soil with drip irrigation and in Harrow peat bags;**
c **cropping in upright bags filled with sawdust;**
d **cropping in rock-wool slabs;**
e **cropping in large pots filled with expanded clay pellets;**
f **test plants in NFT experiencing sudden collapse (due to root death).**

Conventional cropping in soil

Conventional cropping in soil (Plate IV*a*) is the simplest cropping system and involves the planting and raising of a crop as would be done outdoors. The actual planting is an important stage in the growth of the crop. First, dig a trench at least 10 cm deep and 15 cm wide. Then place the plants in soil blocks or peat pots in the trench and heel in with 0.25 L per plant of starter fertilizer solution (10-52-17 in water at 5 g L^{-1}); pull only a little soil around them. Spot-water plants as needed for about 1 week after transplanting. Once the plants are established and the risk of damping off is reduced, irrigate regularly according to soil type and light intensity. On light soils general irrigation begins sooner than on heavier soils.

Type of soil

To achieve maximum production, greenhouse vegetables in general need a well-aerated soil with a high water-holding capacity, rich in nutrients and free of pathogens. Although greenhouse cucumbers can be grown on a wide variety of soils, the most suitable are those classified as loams, sandy loams, and some silty loams, all with a high organic-matter content (Fig. 4). Other types of soils can be used, but they are more difficult and expensive to manage. For example, coarse sandy soils have low water-holding capacity, poor nutrient retention, and poor water cone formation when drip-irrigated; silty soils have an unstable structure that breaks down with heavy watering; and clay loams are poorly drained, difficult to leach, and their structure is damaged by cultivation when wet. Proper management can render almost any soil suitable for greenhouse production. For example, both light and heavy soils can be improved by adding organic matter. If natural drainage is poor, as in most clay, silty clay, and sandy clay loams, a tile or pipe drainage system is needed. The soil provides a medium in which a proper balance exists between air, water, and nutrients. If this balance is ensured, the roots can easily obtain water and nutrients, resulting in rapid growth.

Drainage

Install tile drainage in ground beds to ensure that all excess water drains away. For drainage, use perforated or nonperforated clay tiles, 10 cm in diameter, and lay them with a small space between them to allow for expansion; a few 7.5-cm tiles make effective slip joints for 10-cm tiles. To improve the effectiveness of drainage, cover the tile lines with glass fiber matting made for this purpose or with 2-cm gravel. Set tiles at a depth that prevents their being broken by rototilling or other cultural practices. Place tiles 35 cm deep and 45 cm apart, with a slope of 10 cm for every 150 m of 10-cm clay tiles. The same tiles, with perforations on the bottom or

the sides, are also used for steam sterilization. Loop adjacent rows of tile together at the ends, with elbows and tees for more equalized steaming from line to line. Introduce steam into the rows of tile through a header. This header, with a 50-cm capped riser on each end for steam input, extends across the width of the house and is equipped with nipples 2–3 cm in diameter and about 25 cm long; one nipple corresponds to, and is cemented into, each row of tile. Make both the header and the rows of tile no longer than 15 m, because beyond that length steam condenses into water and gives poor sterilization.

Soil pasteurization

Greenhouse soils may contain weed seeds, insects, and bacteria and fungi that are harmful to the plants. This warning includes potting mixes unless they are guaranteed sterilized or pasteurized by the manufacturer. Soil and potting mixes can be pasteurized to eliminate harmful organisms, ideally without injuring beneficial soil organisms. Soils free of clods, large lumps, and undecomposed crop remains and in fine tilth allow the steam or fumigant to penetrate rapidly and uniformly.

The time–temperature relationships needed to destroy undesirable organisms are as follows:

Weeds (most)	70°–80°C for 15 min.
Insects & mites	60°–71°C for 20 min.
Bacteria (most)	60°C for 10 min.
Fusarium	57°C for 30 min.
Botrytis	55°C for 15 min.
Nematodes	55°C for 15 min.
Rhizoctonia	52°C for 30 min.
Sclerotinia	50°C for 5 min.
Pythium	46°C for 40 min.

Thus, growers can eliminate most organisms of concern (except viruses) using ideal conditions of 60°C for 30 minutes. Heating above 82°C begins to destroy beneficial soil organisms. Soil heated at too high a temperature for too long becomes sterile and subject to a greater degree of infection by pathogens than previously, simply because *all* organisms have been destroyed. Other undesirable effects of over-steaming include

- excessive ammonia release
- manganese toxicity
- high total-salts levels
- destruction of organic matter.

Steam method

Steam is the most common source for heat pasteurization. When pasteurizing soil for vegetable seedlings, growers find it efficient to inject steam into the bottom of a wagon or old truck body filled with soil. After cooling, the pasteurized soil can be moved to the area in which it will be used. For steaming greenhouse soils where the crop is to be grown, growers follow two main techniques. If the ground beds are drained with agricultural tile (top of the tile 30–40 cm below the surface and rows on 40–60-cm centres), steam injected into the tiles effectively pasteurizes the soil to the sides and above them. Covering the area with a plastic sheet enhances the efficiency of this method by confining the steam when it reaches the soil surface. If tiles are not installed, a coarse, well-drained greenhouse soil can be adequately pasteurized by injecting steam directly under a specially formulated plastic "steam tarp." For even distribution inject the steam through a canvas hose or a perforated, flexible field tile. Bury the edges of the tarp 10–12 cm so that it will confine steam up to 41–48 KPa (6–7 psi) pressure. With either steaming method, check the temperature accurately in several locations beneath the plastic, using specially designed thermometers where the sensitive element is attached to the dial by a few metres of cable. A soil temperature reading of 80 °C at a depth of 30 cm sustained for 30 min provides sufficient soil pasteurization.

Aerated steam method

Aerated steam is being used more widely today. In this system live steam is mixed with air in a chamber, and the mixture (at 70°C) is used to pasteurize soil. The lower steam temperatures allow the soil to be pasteurized yet avoid the hazards of oversteaming. Unless there are specific problems, soil temperatures of 70°C adequately destroy most insect and disease organisms.

Electric soil pasteurizers

Electric soil pasteurizers are useful for small volumes of soil when no other method is available. In this method, over-cooking the soil can easily occur because, for the temperature between the finned heat source to reach 82°C, the fins themselves must be at a higher temperature.

Chemical fumigants

With the high cost of steaming, the use of chemical fumigants as a method of soil pasteurizing has become more popular. Each fumigant has a specific rate and activity against soilborne insects, diseases, nematodes, and weeds. Directions for use, as provided by the manufacturer, must be closely followed. Crops in adjoining beds or greenhouses may need guarding

against the drift of toxic vapors from the fumigant. **Recommended fumigants, their use, and rates of application are subject to government regulations, which can vary from province to province. Licensing is required before certain fumigants (e.g., methyl bromide) can be used. Pay strict attention to regulations governing fumigant use and take precautions during application.**

Flooding and leaching

To achieve the best results with steam sterilization, first cultivate the soil and bring its water content to field capacity. The amount of water required varies with the original moisture content of the soil and the soil type but is generally between 20 and 50 L m^{-2}.

Steam sterilization, particularly oversteaming, often releases toxic amounts of ammonia and manganese. The content of other elements, such as potassium, iron, and zinc, may also increase. When soil analysis shows an undesirable excess of soluble salts, leaching with water usually helps to remove an excess of these substances, and to cool the soil following steam sterilization. Use the amounts given in Table 11 as a guide.

Table 11 Leaching requirements after steaming

Electrical conductivity ($\mu S\ cm^{-1}$)		Water required (L m^{-2})	
Saturated-paste method	1:2 water extract	Sandy soils	Other soils
Up to 1.5	Up to 0.5	15	25
1.5–3.0	0.5–1.0	30	50
3.0–5.0	1.0–1.5	70	100
Over 5	Over 1.5	100	150

Notes:

- The numbers suggested for required water (L m^{-2}) also indicate equivalent rates of rain in millimetres.
- The rates apply to leaching and are added to the requirement for bringing the soil to field capacity (usually 20–50 L m^{-2}).
- The rates apply to use of overhead sprinklers at intervals over 2–5 days.
- It is difficult to leach salts from heavy-textured soils, especially if no effort is made to improve their structure.
- If the conductivity before leaching is higher than the recommended range, it must be checked again after leaching and before planting.
- Flooding reduces nitrates and conductivity markedly and may reduce potassium reserves slightly, but it produces little change in other nutrient levels.

Organic matter

A high level of organic matter helps to maintain a stable soil structure and improves the water-holding capacity of the soil. In the past, growers used to steam sterilize greenhouse soils and then add well-rotted manure after sterilization. This procedure reduced the release of ammonia and other toxic substances, and it also helped to reinoculate the soil with beneficial organisms. However, the danger of introducing disease organisms and weed seeds always remained. As an added complication, the use of manure or muck soil as a source of organic matter has the inherent potential for contaminating the greenhouse soil with herbicide residues. The recommended amounts of manure varied from 45 to 225 t ha^{-1}, depending on the kind of manure and the soil conditions. For example, spent mushroom compost has a high nutrient content and can cause soil conductivity problems, whereas undecomposed straw may induce nitrogen deficiency.

Depending on grower experience, intricate planning, and good luck, crops of exceptional vigor and productivity have been achieved in the past with the timely application of manure. However, the success of the crop is not easily predictable because it depends on the timing and quantity of nitrogen release as well as the prevention of high salt and ammonia release from the applied manure. The liberal application of manure, along with the use of straw as mulch, provided also for the release of significant quantities of CO_2. This gas must have contributed further to the impressive productivity of past crops, despite the limited environmental controls of old greenhouse structures.

In recent years, the addition of organic matter has been seen more as a means of improving the soil condition (structure) than of increasing the nutrient content of the soil. In fact, the nutrient content of most manures and other nonstandardized sources of organic matter is extremely variable. Their use is considered a liability rather than an asset because of the unpredictable effects on the crop. Now, the benefit from the circumstantial evolution of CO_2 from decaying organic matter is not as important, because of the widespread use of CO_2 enrichment in modern greenhouses. At present, coarse peat is the most satisfactory material as a source of organic matter. When used to improve the soil conditions, e.g., on new sites, apply peat generously at rates of up to 500 m^3 ha^{-1}. When the soil reaches the desired condition, reduce the rate; the need for an annual dressing remains because soil organic matter decomposes rapidly under glass. Apply loose peat to soil at a yearly rate of 100 m^3 ha^{-1}. Peat is acid, with a pH of about 4, and therefore has the added benefit of reducing the pH of calcareous soils; where the soil is noncalcareous, add ground limestone to the loose peat at a rate of 5 kg m^{-3} to neutralize the peat's acidity. Broadcast peat and lime before the main cultivation and incorporate them into the top 30 cm of the soil.

Control of pH

Greenhouse vegetables generally grow quite well in a wide range of soil pH (5.5–7.5), but a pH of 6.0–6.5 for mineral soils and a pH of 5.0–5.5 for organic soils are generally accepted as optimum. When the pH is too low, add ground calcitic limestone, or an equal amount of dolomitic limestone when the magnesium level in the soil is low, to raise it to a desirable level. Use the rates given in Table 12 only as a guide; the actual lime requirement is best assessed by an appropriate laboratory test.

Usually the pH in most greenhouse mineral soils is above the optimum pH range (6.0–6.5). A simple, though temporary, solution to a high pH problem is to add peat, without neutralizing its acidity with limestone. Peat also helps to maintain a good soil structure, but it must be added yearly to make up for loss through decomposition. If needed, supply more calcium either as calcium sulfate (gypsum), which has no affect on soil pH, or in soluble form (e.g., calcium nitrate), with each irrigation. Adding elemental sulfur, i.e., flowers of sulfur, provides a more long-term solution to a high pH soil. No definite recommendations can be made about how much sulfur to apply; it depends on the buffering (cation exchange) capacity and original pH of the soil, both of which vary from one soil to the next. In general, apply flowers of sulfur at a rate of 50–500 kg ha^{-1}. Theoretically, 320 kg of elemental sulfur could neutralize 1000 kg of limestone, assuming that all sulfur converts instantly to sulfuric acid. However, this conversion, performed by soil microorganisms (*Thiobacillus*), takes time; it goes more rapidly in moist, warm, well-aerated soils. Broadcast and thoroughly mix ordinary ground sulfur with the top 15–30 cm of soil several weeks before planting the crop, because the initial velocity of the reaction may be slow in cold soils.

For acidification of soils, you can also use iron sulfate at rates up to 1500 kg ha^{-1}. When hydrolyzed, this salt releases sulfuric acid, which drastically lowers the pH and liberates some of the iron already present in the soil. At the same time, soluble (i.e., available) iron is added. However, on a weight basis, iron (ferrous) sulfate is four to five times less effective than sulfur and is usually more expensive. Sulfuric acid can be added directly to the soil, but it is unpleasant and dangerous to work with and requires the use of special acid-resistant equipment. In some areas it can be applied by custom suppliers who have the equipment necessary for handling it. Sulfuric acid has the advantage of reacting quickly with the soil.

Under most conditions, only a zone near the plant roots need be acidified, which takes much smaller amounts of chemicals. Use this method particularly with drip irrigation; there the root systems occupy a restricted, well-defined, area of soil. Injecting phosphoric or nitric acid, appropriately diluted for convenience and safety, offers an attractive method for lowering the pH of the soil near the plants. Furthermore, these acids prevent salts from precipitating and clogging the irrigation lines and add useful nutrients to the plants. To determine the rate at which to inject acid, add a known amount of acid to a known volume of

Table 12 Lime requirements for correcting soil pH to 6.5

	Lime (t ha^{-1})		
Soil pH	Sandy loam	Loam, silty loam	Clay loam, organic
6.0	3.0	4.5	6.0
5.5	6.0	9.0	12.0
5.0	9.0	12.0	18.0
4.5	12.0	15.0	24.0
4.0	15.0	18.0	30.0

Note: The rates of lime suggested are for the top 15 cm of soil. If acidity has to be corrected to a greater soil depth, increase the rates accordingly.

water until you obtain the desired pH. Alternatively, start injecting small amounts of acid into the irrigation line while checking the pH with an in-line pH sensor; gradually increase the amount of acid injected until the desired water pH is obtained. When conditions allow, select the regularly applied fertilizers for their ability to lower or increase the soil pH according to individual soil needs. For example, ammonium sulfate and ammonium phosphate tend to decrease the soil pH, whereas calcium nitrate tends to increase it.

Preplant fertilizer application

Apply precrop fertilizers after soil steaming and leaching, and rototill them into the greenhouse soil. Add these fertilizers to the limestone that may be needed for adjusting the pH level of the soil (Table 12). Add as much of the required calcium and phosphorus as possible as a base dressing, because these nutrients store effectively in the soil and their absence from liquid feeds prevents most clogging problems of the irrigation system. Provide the calcium in the form of limestone and the phosphorus in the form of superphosphate, both finely ground. Furthermore, these nutrients, by nature of their source and their ability to bind to soil particles, are released slowly into the soil solution and therefore do not raise the total amount of salts dramatically, nor do they upset the nutrient balance of the soils to which they are added as a base dressing.

Also, supply a good portion of potassium along with magnesium, as base fertilizer; the ratio of potassium to magnesium in the soil should be 2 : 1. Avoid applying nitrogen. Make the final decision on base fertilization after receiving the soil test results and consulting with your horticultural crop adviser. Treat the recommended rates of base fertilizers (Table 13) as a general guide only.

Table 13 Recommendations for base fertilizer

Fertilizer	Amount ($kg\ ha^{-1}$)
Superphosphate (0-20-0, fine grade)	250
Potassium sulfate	500
Magnesium sulfate	250
Add the following in combination, if needed	
Calcitic limestone	800
Peat	800 bales ha^{-1}

Cultivating

The soil needs some cultivation to prepare it for sterilization; to incorporate organic matter, lime, and fertilizers; and to produce planting tilth. Rotary diggers are generally preferred because they provide more uniform cultivation with less damage to the soil structure. However, repeated cultivation at the same depth with rotary diggers can lead to a compacted soil layer, so alter the depth of cultivation occasionally.

Watering

Irrigation is usually of the flood type, although some automated equipment may be used. The objective of watering is to maintain a fully adequate supply of water to the plant roots without soaking the soil to the extent that air cannot get to the roots. Do not wait until the plants start to wilt. A good practice is to dig into the soil and judge how much water remains before starting the next irrigation.

Regular watering on the same day of the week is unwise. The needs of the plants change daily and seasonally. Water young plants planted in the greenhouse in January or February only once every 5–10 days, and then only enough to wet 15–20 cm of the soil. Similar plants growing in June may need five to ten times as much water.

Let the soil texture and structure determine how much water to add at each application. By examining the soil before watering and several hours thereafter, you can assess the effectiveness of the water application.

Scheduling the applications of fertilizer

Besides preplant application, fertilizers must also be added regularly throughout the production season. To apply fertilizers to a growing crop, use the dry form, and broadcast it on most or all the cropped greenhouse soil. Recommended rates are listed in Table 14.

Table 14 Recommended fertilizer application rates for spring or fall crops, in soil

	Stock solution A[a] ((kg ha^{-1})			Stock solution B[a] (kg ha^{-1})		
Week from planting	Potassium nitrate	Calcium nitrate	Ammonium nitrate	10-52-10	20-5-30	Magnesium sulfate
1				150		
2	50	50			100	100
3	50				100	
4	50	100			100	100
5	50				100	
6	100	100			100	100
7	100				100	
8	100	100	50		100	
9	100				100	100
10	100	100	50		100	
11	100				100	
12	100	100	50		100	100
13	100				100	
14	100	100	50		100	
15	100				100	100
16	100	100	50		100	
17	100				100	
18	100	100	50		100	100
19	100				100	
20	100	100	50		100	
21	100				100	
22					150	
23					150	

[a] *Caution*: If fertilizers are first mixed in thick stock solutions before they are applied to the crop, group them as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, because such a mixture forms a thick suspension that can plug watering equipment.

Note: Choose soluble fertilizer formulations that are as free as possible of chlorides, sulfates, and carbonates.

Note that the rates of fertilizer prescribed in Table 14 assume that the fertilizers will be applied over most of the greenhouse soil and that they will *not* be applied in restricted areas close to the plants, possibly through a drip-irrigation system. Calculations can show that if the fertilizer prescribed for week #4, for example, were applied through a drip irrigation system, in a single operation, supplying water at 4 L per plant, the concentration of major nutrients in the fertigation solution would be 685 ppm N, 100 ppm P, 980 ppm K, 190 ppm Ca, and 200 ppm Mg. These concentrations are unacceptably high. Similar calculations show that if the same fertilizers were applied through a drip irrigation system continuously, assuming that 2 L of water were applied per plant per day, then the concentration of the major nutrients in the fertigation

solution would be 195 ppm N, 28 ppm P, 280 ppm K, 54 ppm Ca, and 57 ppm Mg. These concentrations are more reasonable.

However, to repeat, the application rates prescribed for the fertilizers in Table 14 are *not* intended for delivery through a drip irrigation system. (Guidelines for fertilizer application through a drip irrigation system are given in the next section.) The soil has a large buffering capacity, so when fertilizers are spread properly over all the greenhouse ground area, the given rates (Table 14) will bring the soil's fertility to a level that can support a vigorous and productive crop.

Mulching

Mulch the soil when cucumber plants grow about 0.5 m tall and only after soil temperature is sufficiently high. Straw is the most common mulch material, but ground corn cobs are also acceptable. The mulch reduces evaporation and soil compaction. Also, with mulch present, little soil splashes onto plants during watering, which avoids dust in the greenhouse. Furthermore, mulch releases a considerable amount of carbon dioxide as it breaks down, which helps plant growth. Mulch incorporated into the soil at the end of the cropping season also provides useful organic matter. However, mulching with organic byproducts gives rise to the well-known problems associated with adding any organic matter to intensely cultivated soils, as discussed earlier.

In recent years, traditional mulching has not been practiced widely. Instead, a white polyethylene film is used to cover the ground whenever the irrigation method permits it. This mulching alternative has several advantages and is best practiced in conjunction with drip irrigation.

Cropping in soil with drip irrigation

The drip irrigation cropping system (Plate IV*b*) is similar to, but better than, the conventional soil cropping system, because it can be used to control crop growth by regulating the supply of water and nutrients. The system also allows reduced relative humidity in the greenhouse, because not all the soil is irrigated and because the system is compatible with the use of white polyethylene film as a light-reflecting mulch. Resources, including energy, are thus used more efficiently with this system.

In most cases, use common in-line drippers with a standard flow of 2 L h^{-1} and one dripper per plant. However, because of the shallowness and extensiveness of the cucumber root system, consider a 4-L h^{-1} dripper, which usually results in more lateral movement of the irrigation water; even better, provide two drippers (2 L h^{-1} each) per plant.

Microsprinklers, or misters, have also been tried at ground level along the row of plants, with favorable results on root growth, plant vigor, and productivity. However, such irrigation systems, if not properly managed,

can easily lead to overwatering and then to disease outbreaks caused by excessive humidity and plant stem wetness.

Another alternative is to use lay-flat polyethylene tubes (about 5 cm ID), with small holes spaced 10 cm apart. This system usually applies water to a much larger area than the drip system but does not raise the RH as much as a microsprinkler or micromister system. Although fairly inexpensive, the lay-flat tube irrigation system has a short lifespan, which requires its frequent replacement. It is not a good choice for large greenhouses, because the water delivery rates vary significantly along the length of the line (i.e., not pressure compensating).

Irrigate the crop up to four times a day, and use the irrigation system to apply fertilizer to the crop. Fertigation (the application of fertilizer through the irrigation system) is now a popular method of fertilizing greenhouse vegetables. Fertilizers are either dissolved in a large holding tank and the solution pumped to the crop or they are mixed in concentrated stock solutions, which are then incorporated, using fertilizer injectors, into the irrigation water (Tables 15 and 15a).

Several makes and models of fertilizer injectors are available at varying costs and offer varying degrees of fertigation control. A sophisticated fertilizer injection system capable of meeting the nutrient requirements of a series of crops automatically from the same set of stock solutions was developed recently at the Agriculture Canada Research Station in Harrow, Ont. (Plate II).

The Harrow FM uses an IBM-compatible computer to activate a series of dosimetric pumps at varying frequencies for the preprogrammed application of a desired concentration of individual nutrients. It also automatically adjusts the supply of water and nutrients to the crops in accordance with crop and environmental conditions.

Introducing drip irrigation and fertigation has made it necessary to consider the fertilizer needs of a crop in terms of the concentration of fertilizer (and therefore the concentration of nutrients) in the irrigation water rather than on the basis of the cropped area. Furthermore, the recommendations regarding the nutrient content of the fertigation solutions of drip-irrigated crops are based mainly on the physiological responses and commercial productivity of the crops. Most earlier recommendations for fertilizer application to traditionally grown crops in soil were based on estimates of nutrient removal by the crop. Base fertilizers are not normally applied when drip irrigation is used. The exceptions are peat and lime, which may be needed to improve soil structure and adjust soil pH.

Table 15 Fertigation schedule for drip-irrigated cucumbers grown in soil

	Fertilizer in stock solution A[a] (kg 1000 L^{-1})			Fertilizer in stock solution B[a] (kg 1000 L^{-1})			Irrigation	
Week from planting	Calcium nitrate	Potassium nitrate	Ammonium nitrate	Monopotassium phosphate	Magnesium sulfate	Magnesium nitrate	Volume (L $plant^{-1}$ day^{-1})	EC ($\mu S\ cm^{-1}$)
				Spring crop				
1	50			100	25		0.4	1300
2	50	35		15	25		0.6	1400
3	35	50	10	15	25		0.8	1500
4	35	50	15	15	25		1.0	1650
5	35	55	15	15	25		1.2	1700
6	35	60	15	15	25		1.6	1750
7	35	65	15	15	25		2.0	1800
8	35	70	15	15	25		2.2	1850
9	35	70	15	15	25		2.4	1850
10	35	70	15	15	25		2.6	1850
11	35	70	15	15	25		2.8	1850
12–17	35	60	15	15		35	4.0	1650
18–22	35	55	15	15		35	5.0	1600
23–end	35	50	15	15		35	4.0	1550
				Fall crop				
1	50			100	25		0.4	1300
2	50	35		15	25		0.8	1400
3	35	50	10	15	25		1.0	1500
4	35	50	15	15	25		1.2	1650
5–12	35	55	15	15		35	3.0	1650
13–end	35	55	15	15		35	2.0	1600

[a] *Caution*: If fertilizers are first mixed in thick stock solutions before they are applied to the crop, group them as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, as such a mixture results in a thick suspension that can plug watering equipment.

Notes:

- Trace elements must also be added to all the above fertilizer feeds; a typical trace element mix (e.g., Plant Product Chelated Micronutrient mix) contains 7.0% Fe, 2.0% Mn, 0.4% Zn, 0.1% Cu, 1.3% B, and 0.06% Mo; when added to the stock solution at the rate of 1 kg 1000 L^{-1} it contributes to the final solution 0.7 ppm Fe, 0.2 ppm Mn, 0.04 ppm Zn, 0.01 ppm Cu, 0.13 ppm B, and 0.006 ppm Mo, with a 1:100 dilution ratio.
- Dissolve the given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injection at a very low rate and increase the rate of injection progressively, and uniformly on all heads, until the desired EC is achieved. Adjust the pH of the fertigation solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid. Alternatively, dissolve the prescribed fertilizers, including the micronutrient mix, into 100 000 L of water, adjust the pH, and apply directly to the crop.
- The recommended strength of the stock solutions is within the working range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixing ratio is used, double the amount of each fertilizer. Make similar adjustments for fertilizer injectors with other mixing ratios. If the solubility limit of a fertilizer (e.g., potassium nitrate) is exceeded, prepare more than one stock solution of the same fertilizer and divide the amount of the fertilizer equally between the stocks.

Table 15a Nutrient concentration in the final nutrient solution when one part of each of stock solutions A and B, prepared as prescribed in Table 10, are mixed with 98 parts of water (i.e. 1:100 dilution ratio)

Week	Nutrient concentration (ppm)												Expected EC[a] ($\mu S\ cm^{-1}$)
	$N\text{-}NO_3$	$N\text{-}NH_4$	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo	
Spring crop													
1	72	3	235	300	95	25	0.7	0.2	0.04	0.01	0.13	0.006	1300
2	117	5	35	175	95	25	0.7	0.2	0.04	0.01	0.13	0.006	1400
3	140	15	35	233	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1500
4	145	25	35	233	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1650
5	151	25	35	251	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1700
6	158	25	35	270	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1750
7	164	25	35	289	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1800
8–11	170	25	35	308	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1850
12–17	196	25	35	270	67	32	0.7	0.2	0.04	0.01	0.13	0.006	1650
18–22	189	25	35	251	67	32	0.7	0.2	0.04	0.01	0.13	0.006	1600
23–end	183	25	35	233	67	32	0.7	0.2	0.04	0.01	0.13	0.006	1550
Fall crop													
1	72	3	235	300	95	25	0.7	0.2	0.04	0.01	0.13	0.006	1300
2	122	12	35	175	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1400
3	140	15	35	233	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1500
4	145	25	35	233	67	25	0.7	0.2	0.04	0.01	0.13	0.006	1650
5–12	196	25	35	270	67	32	0.7	0.2	0.04	0.01	0.13	0.006	1650
13–end	189	25	35	251	67	32	0.7	0.2	0.04	0.01	0.13	0.006	1600

[a] The EC of the water has been assumed at 300 $\mu S\ cm^{-1}$ and is included.

Cropping in peat and other organic media

Peat is an abundant, readily available, lightweight Canadian resource. It provides good water-holding capacity, drainage, aeration, and biological and chemical stability. Peat has been used alone or combined with other materials such as vermiculite, perlite, turface, polystyrene beads, and other materials, in various mixtures with diverse physical characteristics. Besides a high water-holding capacity, peat has a high cation-exchange capacity and maintains an adequate structure during cropping.

Horticultural-grade vermiculite releases some potassium and magnesium during the crop season, which could be more problematic than beneficial because of reduced control over the availability of those nutrients. However, vermiculite has a high cation-exchange capacity, which increases the buffering capacity of the mix and thus reduces the risk of overfertilization.

On the other hand, perlite, turface, and styrofoam beads are completely inert and do not affect the nutrient availability in the mix other than by improving the degree of aeration. These materials are now

preferred because they do not break down as quickly as vermiculite and thus allow for more exact nutrition of the crop. Recent research has shown that the porosity of peat plus perlite declines steadily over time, but the porosity of peat plus polystyrene does not. Although polystyrene effectively increases the air content of the substrate, much of that air—in the polystyrene beads themselves—is of no use to the plants. Perlite, vermiculite, turface, and styrofoam beads are sterile on delivery because of the high temperatures used during their manufacture.

Sand also behaves almost as an inert material and has been used extensively in the past. Like any soil, it is not recommended unless sterilized.

Sawdust is also an important organic medium for cucumber cropping, especially in Canada. However, this system is described only in general terms (under "Sawdust") because it has already been treated in detail in other publications.

The trough system

After mixing the growing medium, place it in a container. When soilless mixes were first developed, a wooden trough (15–20 cm deep and lined with polyethylene) was the most common container used. A drainpipe laid along the centre of the trough drained the water and acted as a duct for steam during sterilizing (Fig. 14). A layer of gravel provided general drainage and protected the polyethylene during cultivation. Since soilless mixes are naturally low in nutrients, fertilizers must be added to promote optimum plant growth.

Two main methods have been used for supplying fertilizers to crops grown in peat media. The simplest is to add all the nutrients required by the crop as you prepare the peat mix (Table 16).

Table 16 Ingredients for a complete soilless mix based on peat and vermiculite (for trough culture)

Medium	Amount
Peat	0.5 m^3 (2 bales of 0.17 m^3)[a]
Horticultural vermiculite	0.5 m^3 (4.5 bags of 0.11 m^3)
Ground limestone (dolomitic)	7.5 kg
Gypsum (calcium sulfate)	3.0 kg
Calcium nitrate	0.9 kg
Superphosphate 20%	1.5 kg
Epsom salts (magnesium sulfate)	0.3 kg
Osmocote® 18-6-12 (9 months)	5–6 kg
Fritted trace elements (FTE 503)	225 g
Chelated iron (NaFe 138 or 330)	30 g

[a] Expansion of compressed bales is estimated to be 50% above original volume.

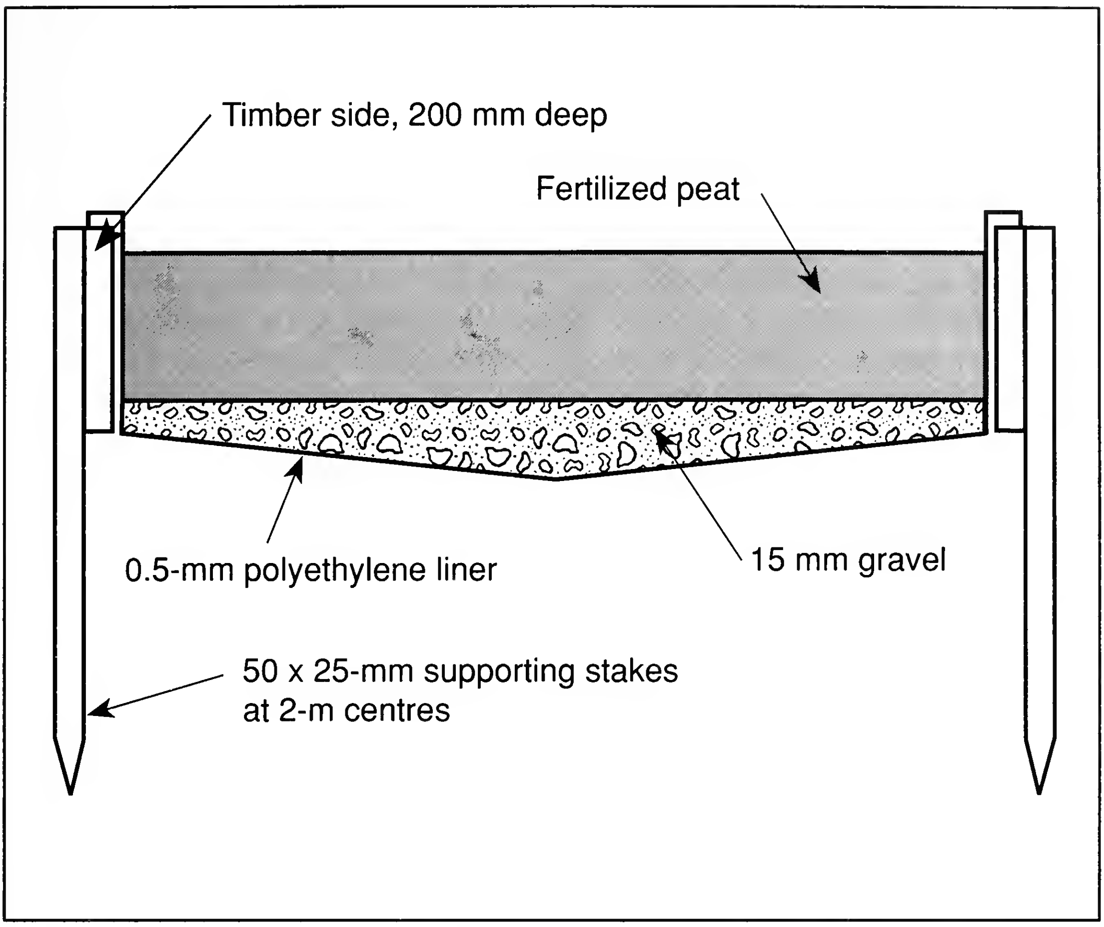

Fig. 14 Trough culture of cucumbers.

The success of this technique depends on slow-release fertilizers providing a continuous supply of nitrogen, phosphorous, and potassium throughout the growing season. The calcium requirements of the crop are met mostly by the calcitic limestone normally added to the peat for pH adjustment. Micronutrients are also added as fritted trace elements, which ensures their slow release during the cropping season. Thus, regular feeding throughout the cropping season is not required unless the presence of nutrient deficiencies indicates a need. The most serious disadvantages of this method are

- the low level of nutrition control
- the potential for crop failure caused by excessive salts resulting from rapid breakdown of the delayed-release fertilizer at high to medium temperatures.

A more popular approach to nutrition is to apply some of the fertilizer when the peat is mixed (Table 17) and to add soluble fertilizers at regular intervals through the irrigation system (Table 18).

The crop's vigor, and the balance between vegetative growth and fruit development, can be adjusted to some extent by the composition of the feed. For example, high-potash (1-0-3.5) feed is normally used to control growth for a short time after planting, when light conditions are poor.

Table 17 Ingredients for a base mixture of peat and vermiculite (1 m^3) (for trough culture and peat bags)

Medium	Amount
Peat	0.5 m^3 (2 bales 0.17 m^3)[a]
Horticultural vermiculite	0.5 m^3 (4.5 bags of 0.11 m^3)
Limestone (pulverized FF)	5.9 kg
Superphosphate 20%	1.2 kg
Potassium nitrate	0.9 kg
Magnesium sulfate	0.3 kg
Chelated iron 10%	35 g
Fritted trace elements (FTE 503 or FTE #302)	110 g

[a] Expansion of compressed bales is estimated to be 50% above original volume.

Table 18 Fertilizer feedings for cucumbers grown in peat troughs (and peat bags)

Type of feed	Ratio (N:P:K)	Fertilizer in stock solution	Amount (kg 1000 L^{-1})	N:P:K:Ca:Mg (ppm)
High potash	1:0:3.5	potassium nitrate potassium sulfate	110 20	145:0:500:0:0
Medium potash with magnesium	1:0:2	potassium nitrate ammonium nitrate magnesium sulfate	90 20 30	175:0:350:0:30
Medium potash with phosphate	1:0.5:2	potassium nitrate monoammonium phosphate ammonium nitrate	90 30 7	175:85:350:0:0
Medium potash with calcium	1:0:2	potassium nitrate calcium nitrate	90 40	175:0:350:70:0
High nitrogen with magnesium	1:0:1	potassium nitrate ammonium nitrate magnesium sulfate	65 50 30	250:0:250:0:30
High nitrogen with phosphate	1:0.5:1	potassium nitrate monoammonium phosphate ammonium nitrate	65 45 33	250:125:250:0:0
High nitrogen with calcium	1:0:1	potassium nitrate calcium nitrate ammonium nitrate	65 45 28	250:0:250:85:0

Note: Stock solutions have been formulated assuming that a fertilizer injector with a feeding ratio of 1:100 (one part stock per 100 parts of water) is used to incorporate one stock solution at a time into the irrigation water. Alternatively, dissolve the recommended fertilizers in each feed in 100 000 L of water for direct application to the crop.

Conversely, high-nitrogen (1-0-1) feed is used to maintain adequate vigor throughout much of the summer, when light and productivity are high. A major difference between the feeding requirements of peat- and soil-grown crops is the need for a regular supply of phosphate; this nutrient readily leaches from peat and has to be replaced to maintain adequate levels. Alternating a phosphate-containing feed (e.g., 1-0.5-2) with a standard feed, such as 1-0-2, supplies phosphate throughout the season. Phosphorus can also be supplied continuously in the form of a special phosphate-containing feed, but this system necessitates supplying calcium or magnesium in separate feeds. Always remember that concentrated solutions containing calcium that come in contact with phosphate-containing solutions can result in insoluble calcium phosphate, which blocks the irrigation system. Likewise, magnesium sulfate should not be mixed in high concentrations with phosphate-containing feeds. Minor elements are generally provided in peat substrates as glass-fritted mixes that release their nutrients slowly over a cropping season. Correct trace-element deficiencies by applying chelated trace element mixes.

Apply chelates either continuously in the liquid feed or as a foliar spray for corrective action. The rate used depends on the product. It is usually best to follow the manufacturer's recommendations. In general, the feeding guidelines already given in this publication should suffice for crops grown in peat substrate throughout the season. However, if nutrient levels in the substrate become too high or too low, reduce or increase the strength of the liquid feed to compensate accordingly. Ideally, use a multifertilizer injection system for supplying optimum water and nutrient to the substrate in accordance with the needs of the crop (e.g., HFM, see Plate II).

If an initial peat-substrate analysis shows nutrient levels outside the acceptable ranges, the medium may still be suitable for vegetable growing, provided that you modify the feeding program to bring the nutrient status back within acceptable limits. After attaining an optimum analytical range for the peat substrate, devise a feeding program that maintains optimum nutrient levels in the substrate. In general, apply the medium potash with phosphate feed (i.e., 175-85-350-0-30), alternatively with the medium potash with magnesium (i.e., 175-0-350-0-30) and with the medium potash with calcium (i.e., 175-0-350-70-0). This mixture will provide an average feed of 175 ppm N, 42 ppm P, and 350 ppm K, along with 35 ppm Ca and 15 ppm Mg.

Peat bags

Plastic bags filled with a peat-based medium are now generally available. Each peat bag, which measures 35 cm × 105 cm when flat and contains 42 L of fertilized peat (or a mixture of peat with vermiculite, perlite, or polystyrene). Each can support up to two cucumber plants as long as

regular watering and fertilizing through a drip irrigation system are provided.

Cover the greenhouse floor with polyethylene film and lay the bags on it. Some growers use a double-layered polyethylene material as a floor covering—a black bottom layer to prevent weed growth and a white top layer to reflect sunlight into the crop canopy. Make two or three 4-cm slits in the sides of the bags to provide drainage for the wet medium. The planting depth in the peat substrate is an important factor that affects later growth. The shallower the depth of peat, the more critical the planting depth becomes; a permanent reservoir of water makes part of the peat bag unavailable for active root growth. This water reservoir develops below the level of the drainage holes. A minimum substrate depth of about 10 cm, a planting depth of 2.5 cm, 5 cm of drained peat beneath the pot, and a water reservoir of 2.5 cm below the drainage level are recommended. Research and practical experience have shown that the upright bags are preferable because they provide a greater depth of useful substrate, which translates into stronger root systems, less water stress, and higher productivity than the lay flat (bolster type) peat bags. Upright bags can conveniently be made by cutting, and sealing one side of, appropriate lengths from a 45-cm-wide (when flat) black (or coextruded black and white) polyethylene tube.

Two aspects of the general culture in peat bags differ from those of soil: watering and feeding. Watering crops grown in peat is easy, provided you

- follow some basic rules
- examine the moisture content of the peat substrate frequently, and
- take appropriate action when necessary.

Watering

Crops in peat may be easier to water than crops grown in soil because the moisture content of the latter is more difficult to assess; also the drainage characteristics of the soil and subsoil make decisions on watering less certain. Because peat bags contain only a small volume of growth medium, they offer a much lower water-holding capacity than most soils. Failure to apply water when needed can therefore have a more rapid detrimental effect on the crop than with soil-grown crops. The following recommendations apply to watering crops grown in peat bags:

- Use a drained peat bag with a water reservoir beneath.
- Provide additional irrigation outlets to areas that need extra water.
- Maintain an efficiently operating irrigation system by preventing or clearing blockages as soon as they occur.
- Check the moisture level of the substrate frequently and modify the watering regime if necessary.
- Vary the frequency of watering rather than the quantity applied each time, so that the substrate aerates between waterings and the moisture content remains uniform from one bag to another.

A faulty watering program leads to waterlogging, excessive drying back, and excessive variation of moisture from bag to bag. Waterlogging is easy to detect, as it results in slow growth and thin plant heads. When this problem persists, the plants develop yellow heads characteristic of iron deficiency. Waterlogging problems usually develop when the watering regime does not allow enough time for proper soil aeration between applications. An excess amount of water applied on one occasion may not matter, as the surplus drains to waste, but a second application made before the substrate has dried to its normal minimum water content reduces root action and starts the cycle of waterlogging. Regular and frequent checks to control water frequency help to avoid this problem. Once waterlogging has occurred and the plants show symptoms, correcting the problem is a slow process; hold back the water to the substrate until it has dried to its normal minimum level, however long this takes. Invariably, crop yield declines while the problem is corrected.

The problem of excessive dryness is equally serious but just as easy to avoid, provided the irrigation system works effectively and you allocate sufficient time to manage the watering program. If the medium often dries to below the normal minimum water level, when water can no longer be squeezed out by hand, plant growth will be impaired, especially if the salt content of the medium is high. Media that are frequently allowed to dry too much also cause a general stunting of growth and considerable yield loss. The remedy is easy—apply more water by increasing the frequency of irrigation. Initial recovery may take several days; nothing can be gained by applying large volumes of water at every single irrigation, as most of it will run off to waste.

The third potential problem comes from excessive variation in water content within the crop. The application of water can never be accurate enough to cover all variation within a crop, and extreme imbalances can develop. In addition, fast-growing plants can produce their own localized water-deficiency problems, and weak, diseased, or removed plants can precipitate local waterlogging. Where the problem is not extensive, rebalance a crop by occasional hose watering to top up dry areas and by temporarily removing one or more irrigation outlets from areas of waterlogging. Occasionally inducing waterlogging can prevent or correct large-scale water imbalance, but use the technique only on an actively growing crop with a strong root system. This practice is also valuable for leaching out excess salts from the substrate. As a general rule for irrigation, apply water until the driest area of the crop has recovered its full water requirement at each application. In this way, you can prevent water from building up, and areas of substrate with a lower water requirement drain off any surplus without danger.

Anyone considering peat substrate culture of greenhouse cucumbers for the first time should be aware that watering requires considerable managerial effort and a dependable irrigation system. You might decide that the risk of mistakes does not justify the change from soil to peat substrates. However, the fact that water management errors in substrate culture quickly manifest themselves into visible symptoms makes peat

substrate and other soilless culture systems attractive. In soil culture, incorrect watering usually becomes evident only after the crop has changed its growth habit significantly. Consequently, although soil has a greater water-holding and buffering capacity, greater crop losses can still be incurred without the grower's awareness of any mistakes having been made. A competent grower using substrate culture can see potential errors in irrigation when they first appear in the peat mixture and correct them before they have any effect on the plants. The recent development of computerized irrigation controllers equipped with properly adapted soil water tensiometers has made the scheduling of irrigation of crops grown in peat bags much simpler. Significant water and nutrient savings have resulted while minimizing excessive nutrient leaching into the environment.

Feeding

Nutrition is the other major area in which peat-grown cucumbers differ significantly from cucumbers grown in soil. Peat substrates have a much lower buffering capacity than most soils in relation to both major and minor elements. The grower therefore needs to monitor continually the nutrient availability in the substrate and to adjust accordingly the composition of the feed applied to it. This work requires a rapid and reliable analytical service, and a dependable and accurate technique for frequent application of fertilizers. The results of peat substrate analysis enable you to take corrective action for an optimum root environment before adverse symptoms appear in the crop. To depend on crop symptoms alone for determining a necessary change in the feeding program greatly increases the risk of yield loss. As important as the analytical service is the ability of the grower to interpret the results and take any corrective action needed. Although the initial nutrient levels in peat substrates vary according to the supplier, the source, and type of peat used, regard the ranges in Table 19 as normal and use them only as a guide.

Table 19 Desirable nutrient levels in the substrate of peat bags, based on a substrate-to-water dilution of 1 : 1.5

Nutrient	Concentration (ppm)
Nitrogen (nitrate)	30–80
Phosphorus	20–50
Potassium	140–400
Calcium	140–200
Magnesium	25–35
Acidity (pH)	5.5–6.6
Electrical conductivity ($\mu S\ cm^{-1}$)	1000–2500

The results of peat analysis vary according to sampling and analysis procedures. The comparability of any peat-sample analytical results with the guidelines in Table 19 therefore depends on the following conditions:

- Take a peat sample from the full depth of substrate in the bag.
- Locate the sampling point near a growing plant and let it extend through the rooting zone.
- Take several samples throughout the greenhouse area to be tested and mix them together to supply at least 0.5 L of substrate for analysis.
- Do not take samples immediately after watering or from areas that are clearly wetter or drier than the average for the house.
- Bring peat substrate samples taken as described above to a uniform water content either by adding distilled water to them or by allowing them to dry out as needed before proceeding with analysis; on squeezing moderately a handful of peat, the release of a small amount of water indicates a desirable water content.
- Perform all analytical tests on an aqueous suspension of the peat substrate sample, at a peat-to-distilled-water ratio of 1 : 1.5, by volume (Table 19).

The recommendations already given in Tables 17 and 18, for the composition of the peat mix and the liquid nutrient feeds, also apply to cucumber cropping in peat bags.

Recycling

Experimental and commercial evidence suggests that you can recycle the peat substrate without reducing the crop yield. However, the following factors can influence the cropping potential of recycled peat substrate:

- the level and uniformity of nutrients in the peat
- the salt level in the medium
- the pest and disease status of the substrate.

If you plan to reuse the bags, reduce the strength of the fertilizer feed by half, starting about 4 weeks before the planned termination of the first crop; apply plain water during the last 1–2 weeks. This extended period of gradual nutrient leaching reduces the nutrient levels in peat substrates. The degree to which the nutrient levels fall varies depending on how easily they leach. For example, in a well-leached substrate the nitrate level is very low, the phosphate and potassium levels are low, and the calcium and magnesium levels remain high.

To minimize the problems caused by a lack of uniformity in the nutrient content of reused peat bags, sterilize the leached peat medium in bulk. After sterilization, analyze the peat medium and add base fertilizers as needed before rebagging. The principles of steaming are similar for both soil and peat. The objective is to destroy harmful organisms while preserving most of the beneficial organisms and nutrients, without allowing salts to build up. Therefore, avoid excessive steaming. Raising the temperature through the substrate to 82°C for

20 min is all that is needed. As with soil, the peat should be neither too wet nor too dry at steaming, otherwise the cost of the operation is unnecessarily high or its efficiency unnecessarily low. Because of the small amount of peat substrate used in a greenhouse, compared with soil, both the energy and labor expended in steaming peat are considerably less.

The Harrow peat-bag system

In the early 1980s, the Harrow Research Station developed a peat-bag system for producing greenhouse cucumbers (Plate IV*b*). The recommendations for the peat-based growth medium and the corresponding fertigation schedule and nutrient concentrations are presented in Tables 20, 21, and 21a, respectively.

Table 20 Peat-bag growth medium recommended for cucumbers

Mixes	Ingredients	Quantities
A	Peat (57% of total volume)	3.0 bales (0.17 m^3)
	Vermiculite (25% of total volume)	3.0 bags (0.11 m^3, 7 kg)
	Perlite (18% of total volume)	2.0 bags (0.11 m^3, 7 kg)
B	Limestone (pulverized FF)	7.0 kg
	Ground limestone (dolomitic)	5.0 kg
	Ground superphosphate (20% phosphorus)	1.5 kg
	Potassium sulfate	1.0 kg
	Fritted trace elements (FTE 302)	150.0 g
C	18-6-12 slow-release (9-month) fertilizer	2.0 kg
D	Potassium nitrate	0.6 kg
	Magnesium sulfate	0.3 kg
	Chelated iron (iron EDTA, 13% iron)	35.0 g
E	Wetting agent	0.1 L

Note: Mix ingredients of A and B separately; dissolve ingredients of D and E in 20 L each of water; combine A, B, and C and wet with solutions D and E, adding more water (if needed) as you mix. This mixture provides enough medium for at least 32 peat bags measuring 0.35 m × 1.05 m, when flat.

Table 21 Fertigation schedule for cucumbers grown in Harrow peat bags

	Fertilizer in stock solution A[a] (kg 1000 L^{-1})			Fertilizer in stock solution B[a] (kg 1000 L^{-1})			Irrigation	
Week from planting	Calcium nitrate	Potassium nitrate	Ammonium nitrate	Monopotassium phosphate	Magnesium sulfate	Magnesium nitrate	Volume (L $plant^{-1}$ day^{-1})	EC (μS cm^{-1})
				Spring crop				
1	50			100	25		0.4	1300
2	50	35		30	25		0.6	1450
3	50	50	10	30	25		0.8	1750
4	50	50	15	30	25		1.0	1850
5	50	55	15	30	25		1.2	1900
6	50	60	15	30	25		1.4	1950
7	50	65	15	30	25		1.6	2000
8	50	70	15	30	25		1.6	2050
9	50	70	15	30	25		1.8	2050
10	50	70	15	30	25		2.0	2050
11	50	70	15	30	25		2.0	2050
12–17	50	60	15	30		35	2.0	1950
18–22	50	55	16	30		35	3.0	1900
23–end	50	50	15	30		35	2.6	1850
				Fall crop				
1	50			100	25		0.6	1300
2	50	35		30	25		0.8	1450
3	50	50	10	30	25		1.2	1750
4	50	50	15	30	25		1.6	1850
5–12	50	55	15	30		35	2.0	1900
13–end	50	55	15	30		35	1.4	1900

[a] *Caution*: If you first mix fertilizers in thick stock solutions before applying them to the crop, group them as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, as such a mixture results in a thick suspension that can plug watering equipment.

Notes:

- Trace elements must also be added to all the above fertilizer feeds; a typical trace element mix (e.g., Plant Product Chelated Micronutrient mix) contains 7.0% Fe, 2.0% Mn, 0.4% Zn, 0.1% Cu, 1.3 B, and 0.06% Mo and, when added to the stock solution at the rate of 2 kg 1000 L^{-1}, contributes to the final solution 1.4 ppm Fe, 0.4 ppm Mn, 0.08 ppm Zn, 0.02 ppm Cu, 0.26 ppm B, and 0.012 ppm Mo, with a 1:100 dilution ratio.
- Dissolve the given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injecting at a very low rate and increase the rate of injection progressively, and uniformly on all heads, until the desired EC is achieved. Adjust the pH of the fertigation solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid. Alternatively, dissolve the prescribed fertilizers, including the micronutrient mix, into 100 000 L of water, adjust the pH, and apply directly to the crop.
- The recommended strength of the stock solutions is within the working range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixing ratio is used, double the amount of each fertilizer. Similar adjustments can be made for fertilizer injectors with other mixing ratios. If the solubility limit of a fertilizer (e.g., potassium nitrate) is exceeded, more than one stock solution of the same fertilizer can be prepared and the amount of the fertilizer divided equally between the stocks.

Table 21a Nutrient concentration in the final nutrient solution when one part of each of stock solutions A and B, prepared as prescribed in Table 16, are mixed with 98 parts of water (i.e., 1:100 dilution ratio)

Week	Nutrient concentration (ppm)												Expected EC[a] ($\mu S\ cm^{-1}$)
	$N\text{-}NO_3$	$N\text{-}NH_4$	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo	
						Spring crop							
1	72	3	235	300	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1300
2	117	5	69	218	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1450
3	162	22	69	275	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1750
4	170	30	69	275	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1850
5	176	30	69	294	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1900
6	182	30	69	313	95	25	1.4	0.4	0.08	0.02	0.26	0.012	1950
7	188	30	69	332	95	25	1.4	0.4	0.08	0.02	0.26	0.012	2000
8–11	194	30	69	351	95	25	1.4	0.4	0.08	0.02	0.26	0.012	2050
12–17	182	30	69	313	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1950
18–22	176	30	69	294	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1900
23–end	170	30	69	275	95	32	1.4	0.4	0.08	0.02	0.26	0.012	1850
						Fall crop							
1	72	3	235	300	95	25	1.4	0.4	0.08	0.04	0.26	0.012	1300
2	117	5	69	218	95	25	1.4	0.4	0.08	0.04	0.26	0.012	1450
3	162	22	69	275	95	25	1.4	0.4	0.08	0.04	0.26	0.012	1750
4	170	30	69	275	95	25	1.4	0.4	0.08	0.04	0.26	0.012	1850
5–end	176	30	69	294	95	32	1.4	0.4	0.08	0.04	0.26	0.012	1900

[a] The EC of the water has been assumed at 300 $\mu S\ cm^{-1}$ and is included.

Sawdust

In the 1950s and 1960s, the Saanichton and Agassiz research stations developed a method of cropping greenhouse cucumbers in sawdust (Plate IV*c*). This method received general commercial acceptance in British Columbia, and to some extent in Alberta, in the 1970s and 1980s, but it is now being replaced by rock wool. Some advantages of sawdust culture are its low cost, light weight, and its wide availability. Although rock wool also claims some of these qualities, sawdust could again receive renewed attention because it is easier to dispose of than rock wool.

The sawdust used as a growing medium in the past was derived from Douglas-fir and western hemlock. Sawdust from western red cedar proved toxic, especially when fresh, so avoid its use. Other organic or inorganic media can be mixed with sawdust to improve its chemical and physical properties. However, the various substrate mixtures must be formulated and tested on a small scale under well-controlled conditions. The uncontrolled distribution of a many organic media mixtures with diverse chemical and physical characteristics confuses growers and detracts from the profitable use of this valuable Canadian resource.

Use only the horticultural-grade sawdust and ensure that it is free from contaminants that are toxic to plants (e.g., antifungal chemicals used by the lumber industry). If in doubt, have a sample of the sawdust analyzed and ensure that neither the EC nor any particular element (e.g., manganese) are outside normal levels.

Place the sawdust in troughs, beds, upright bags, bolsters, or even large pots. Regardless of the container, use a minimum of 10 L of medium for each plant. The practices followed in sawdust culture are similar to those described earlier for peat.

Apply fertilizer in two ways: either, supply all nutrients in solution at each irrigation (Tables 22 and 22a); or, incorporate some of the fertilizer into the growth medium before planting and deliver the rest through the irrigation system (Tables 23 and 23a).

Table 22 Fertilizer application rates for cucumber production in unfertilized sawdust

		Nitrogen level in final solution		
Stock[a]	Fertilizer	N at 126 ppm	N at 168 ppm	N at 210 ppm
		Amount of fertilizer in final solution (g 1000 L^{-1})		
A	Potassium nitrate	160	500	550
	Calcium nitrate	680	680	680
	Ammonium nitrate	–	–	100
B	Potassium sulfate	360	44	–
	Magnesium sulfate	500	500	500
		Volume of stock added (mL 1000 L^{-1})		
C	Trace element stock[b]	220	220	220
	Phosphoric acid (75%)[c]	100	100	100

[a] *Caution*: If you first mix fertilizers in thick stock solutions before applying them to the crop, group them as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, as such a mixture results in a thick suspension that can plug watering equipment.

[b] The trace element stock solution is prepared by dissolving the following elements in 1 L of warm water: 100 g iron chelate (7% Fe), 15 g manganese sulfate, 12 g boric acid, 2.2 g zinc sulfate, 0.6 g copper sulfate, and 0.2 g molybdic acid. When this trace element stock solution is added to the final nutrient solution at a rate of 220 mL L^{-1}, the concentration of trace elements in the final nutrient solution is as follows: 1.54 ppm Fe, 1.07 ppm Mn, 0.46 ppm B, 0.11 ppm Zn, 0.034 ppm Cu, and 0.023 ppm Mo.

[c] Concentrated phosphoric acid (75%) can be carefully added directly to the final nutrient solution without prior dilution.

Table 22a Concentrations of nutrients provided by the final solution when fertilizers are added at the rates prescribed in Table 22

Nutrient	Nutrient level in final solution (ppm)		
	N at 126 ppm	N at 168 ppm	N at 210 ppm
Nitrogen (from NO_3)	119	162	189
Nitrogen (from NH_4)	7	6	21
Phosphorus	47	47	47
Potassium	208	208	208
Calcium	129	129	129
Magnesium	50	50	50
Iron	1.54	1.54	1.54
Manganese	1.07	1.07	1.07
Boron	0.46	0.46	0.46
Zinc	0.11	0.11	0.11
Copper	0.034	0.034	0.034
Molybdenum	0.023	0.023	0.023

Table 23 Fertilizer application rates for cucumber production in fertilizer-amended sawdust

Fertilizer	Nitrogen level in final solution		
	N at 126 ppm	N at 168 ppm	N at 210 ppm
	Amount of fertilizer in final solution ($g\ 1000\ L^{-1}$)		
Potassium nitrate	550	550	550
Ammonium nitrate	160	280	410
	Volume of stock added ($mL\ 1000\ L^{-1}$)		
Trace element stock[a]	220	220	220
Phosphoric acid (75%)[b]	100	100	100

[a] The trace element stock solution is prepared by dissolving the following elements in 1 L of warm water: 100 g iron chelate (7% Fe), 15 g manganese sulfate, 12 g boric acid, 2.2 g zinc sulfate, 0.6 g copper sulfate, and 0.2 g molybdic acid. When this trace element stock solution is added to the final nutrient solution at a rate of 220 mL L^{-1}, the concentration of trace elements in the final nutrient solution is as follows: 1.54 ppm Fe, 1.07 ppm Mn, 0.46 ppm B, 0.11 ppm Zn, 0.034 ppm Cu, and 0.023 ppm Mo.

[b] Concentrated phosphoric acid (75%) can be carefully added directly to the final nutrient solution without prior dilution.

Table 23a Concentrations of nutrients provided by the final solution when fertilizers are added at the rates prescribed in Table 23

Nutrient	Nutrient level in final solution (ppm)		
	N at 126 ppm	N at 168 ppm	N at 210 ppm
Nitrogen (from NO_3)	98	121	140
Nitrogen (from NH_4)	27	47	70
Phosphorus	47	47	47
Potassium	209	209	209
Calcium	0	0	0
Magnesium	0	0	0
Iron	1.54	1.54	1.54
Manganese	1.07	1.07	1.07
Boron	0.46	0.46	0.46
Zinc	0.11	0.11	0.11
Copper	0.034	0.034	0.034
Cobalt	0.023	0.023	0.023

The fertilizer rates described in Table 22 are recommended for cucumber production in unfertilized sawdust. Those described in Table 23 are recommended for cucumber production in sawdust enriched with superphosphate (0-19-0) at 2.4 kg m^{-3} and dolomitic limestone at 4 kg m^{-3}. To ensure the long-term availability of calcium and magnesium, supply half the limestone ground coarse and half ground fine.

You can prepare the solutions described in Tables 22a and 23a in two ways. One is to dissolve the fertilizers at the prescribed rates in water and apply the resulting nutrient solution directly to the crop. The other is to prepare concentrated stock solutions (e.g., 100 times the prescribed rates) and incorporate these solutions into the irrigation water using a fertilizer injector with a 1:100 mixing ratio. Table 24 outlines revised quantities both for making stock solutions for dilution at a mixing ratio of 1:100 before application, and for preparing the final solution directly. Always remember that calcium and sulfates cannot be mixed together at high concentrations without some precipitation of calcium sulfate, and therefore at least two stock solutions must be prepared.

Table 24 Fertilizer application rates for cucumber cropping in sawdust (according to the revised recommendations of the B.C. Ministry of Agriculture, Fisheries and Food)

Stock	Fertilizer	Fertilizer in stock sol. (for 1:100 dilution) (kg 1000 L^{-1})	Fertilizer in final solution (g 1000 L^{-1})
A	Potassium nitrate	50.0	500.0
	Calcium nitrate	75.0	750.0
	Iron chelate (7% Fe)	1.4	14.0
B	Monopotassium phosphate	20.0	200.0
	Potassium sulfate	9.6	96.0
	Magnesium sulfate	25.0	250.0
	Manganese sulfate (28% Mn)	0.107	1.07
	Boric acid (20.5% B)	0.243	2.43
	Zinc sulfate (36% Zu)	0.027	0.276
	Copper sulfate (25% Cu)	0.012	0.120
	Molybdenum (54% Mo)	0.009	0.092

Note: When the fertilizers are added at the prescribed rates, the final solution will deliver nutrients at the following concentrations: 168 ppm N (NO_3), 7 ppm N (NH_4), 46 ppm P, 286 ppm K, 142 ppm Ca, 25 ppm Mg, 1.0 ppm Fe, 0.3 ppm Mn, 0.5 ppm B, 0.1 ppm Zn, 0.03 ppm Cu, and 0.05 ppm Mo.

Straw bales

The use of straw bales was popular a few decades ago in several countries, especially the United Kingdom, as a soilless medium for cucumber production where soilborne diseases seriously limited productivity. The universal availability and low cost of straw made it an attractive alternative to soil for several years, but as new and better substrates became available it gradually lost its appeal. Today straw is used only by growers using a low-input cropping system in old greenhouses. A brief description is given here both for historical reasons and for the benefit of growers who may not have access to modern greenhouse technology.

For long-term crops, use bales of wheat straw (each bale contains about 20 kg of straw packed heavily in the form of a brick and held together by polypropylene string). For short-term crops, use barley or oat straw, which breaks down faster. The straw must be completely free of all traces of herbicide residue (especially the plant hormone type), which can distort growth or totally destroy the crop. Place the bales end-to-end, in rows, in either shallow trenches (5–10 cm) or on leveled ground, which has been first covered with white polyethylene film; row spacing depends on the training system to be followed. Condition the straw bales for 2–3 weeks before planting the crop. Conditioning entails

- adding water to initiate fermentation of the straw
- "fueling" the fermentation with nitrogenous fertilizers

- leaching any excessive salts released by the fermentation process
- dressing the straw substrate with base fertilizers.

The day-by-day procedure for preparing the straw bales for planting follows:

Day 1: move straw bales into the greenhouse, raise greenhouse temperature to a minimum of 12–13°C to promote fermentation.

Days 2–5: apply water daily, in frequent small applications to thoroughly wet the straw; dry straw is difficult to wet.

Days 4–5: apply (spread over) 120–150 g of ammonium nitrate fertilizer on each straw bale.

Days 6–8: apply more water daily in frequent small applications to prevent nitrogen leaching.

Day 9: apply more nitrogen (ammonium nitrate at 70–80 g per bale); by now the temperature of the straw, internally, may have reached 50–60°C.

Days 10–12: apply more water.

Day 13: test total salts in straw bale and leach, if necessary.

Day 14: apply base fertilizers at the rate (per bale) of 70–80 g ammonium nitrate, 200 g of triple superphosphate, 100 g of magnesium sulfate, and 400 g of potassium nitrate.

Days 14–15: apply water to wet-in the base fertilizers.

Days 16–17: prepare soil or soilless mix and apply as a top cap (5–10 cm of growth medium applied over the bales to facilitate planting and to assist in establishing a good conduct between the root system of the transplants and straw substrate).

Days 18–20: plant crop, provided the temperature of the straw has subsided to below 35°C.

As plants grow, twist them loosely around the crop support strings, which must be left slack to prevent the roots from pulling out of place when later in the season the straw decomposes further and settles. After planting the crop, limit fertilizer application to nitrogen feeding, as was done originally by the pioneers of this production system. Table 25 outlines a simple schedule, and Table 25a provides an analysis of the nutrient concentration achieved using this method.

Table 25 Fertilizer application schedule for cucumbers grown in straw bales

Weeks	Fertilizer[a]		
	Ammonium nitrate	Potassium nitrate	Magnesium sulfate
1–3	17		
4–6	40		
7–end	27	7	7

[a] Fertilizer in stock solution at kg 1000 L^{-1}, to be applied with a fertilizer injector with 1:100 ratio.

Table 25a Nutrient concentration in the final nutrient solution when fertilizers are applied as prescribed in Table 25

Weeks	Nutrient concentration in final solution (ppm)			
	$N\text{-}NO_3$	$N\text{-}NH_4$	K	Mg
1–3	28	28		
4–6	78	78		
7–end	55	46	27	7

The original straw-bale culture system as described above was later improved by substituting the use of solid fertilizers with continuous liquid fertilizer feeding. In this method, about 10–14 days are still needed for completely wetting the straw bales with a nutrient solution of low EC (1600 $\mu S\ cm^{-1}$) having a 2-1-2 analysis; the initial break-down (fermentation) of the straw is minimized. After planting, continue liquid feeding for 2–5 weeks at a lower EC of 800 $\mu S\ cm^{-1}$; then raise the EC again to 1600 $\mu S\ cm^{-1}$.

The main reasons for the recent decline in the use of straw bales as a substrate for cucumber production are

- the time needed to prepare the straw bales and consequently the loss in time between crops
- the difficulties in controlling the speed and timing of the fermentation and, therefore, nutrient use or release by the straw
- the bulkiness of the medium resulting in loss of usable space for the vertical training of the plants
- the high labor rquirement in handling the bales

- the availability of more convenient and inert media, conducive to much more accurate nutritional control.

Straw-bale culture offers many advantages and, if some of the disadvantages were minimized, this substrate could become popular again. Some attractive features of the straw-bale culture system are

- straw is an inexpensive natural organic product, widely available, easily recyclable, and nonpolluting
- the gradual fermentation of straw, when controlled successfully, provides heat that helps maintain warm roots and contributes to the overall energy needs of the greenhouse
- the fermentation of straw provides carbon dioxide which helps raise the CO_2 concentration in the greenhouse with beneficial effects on productivity
- straw provides excellent aeration for root growth and ample space for root development.

Further research could develop better methods for controlled straw fermentation using our vastly improved greenhouse environment and fertigation controls. Developing better ways for continuously applying complete nutrient solutions could remove the need for the 2–3 week waiting period before planting the crop. Quicker turnaround would eliminate one of the most serious obstacles to the profitable use of straw bales in cucumber production.

Cropping in rock wool and other inert media

Rock wool consists of a fibrous material produced from a granitelike rock known as diabase, or basalt. During manufacture the minerals are melted at about 1600°C and transformed into fibers bonded together with resins. Initially made for the building trade as an insulator, this spongy material has recently become available in cubes or slabs; an added wetting agent makes it water-absorbent for horticultural use (Plate IV*d*).

Other inert products that have been used as growing media, singly or combined, include perlite, vermiculite, polyurethane (Oasis®), expanded clay pellets, and polystyrene beads. All these inert materials are made in the same way as rock wool and share physical and chemical characteristics. All are sterile (free of pathogens and weed seeds). They offer a low cation-exchange capacity and a high water-holding capacity. They permit adequate root aeration and a high degree of control over watering and feeding. Furthermore, because of their light weight and ease of handling, the interval between crops can be shorter than usual. Finally, they allow energy savings for two reasons: first they eliminate soil steaming; second their use makes root heating practical. The latter allows for more precise control of air temperature on the basis of minimum temperature requirements of the shoots rather than the roots.

Vermiculite cannot be considered entirely inert because it contains some potassium and magnesium, which gradually become available to plants as it breaks down. Other not entirely inert media that have been used commercially as growth substrates include various grades of sand and gravel.

Rock wool is by far the most important inert medium. It is used commercially around the world, and a wealth of information on its use is available from experienced growers and plant scientists. However, with proper management, all the media mentioned have similar yield potential. Because most of the technology used in producing greenhouse cucumbers in inert media is similar, the detailed procedure described for rock wool also applies to managing the other media. References are made to other media where necessary. The general guidelines on "Watering" discussed under "Peat bags" apply also to other soilless media used in small quantities and must always be kept in mind.

Rock wool

Horticultural-grade rock wool is manufactured in several countries (United Kingdom, Denmark, Holland, Germany, France, United States, and recently, Canada) under various trademarks (e.g., Basalan, Capogro, Grodan, Pargro). Although the chemical composition of rock wool varies with the manufacturer, the ingredients making up the fibers are unavailable to the plants, so all nutrients must be added regularly to the crop in solution.

Rock wool is available in the form of slabs, blocks, or granules. The rectangular slabs vary in length and width but are usually 7.5 cm deep for raising long-season crops such as tomatoes, cucumbers, peppers, and eggplant, among others. Typical dimensions are 100 × 15 × 7.5 cm, 90 × 15 × 7.5 cm, 100 × 20 × 7.5 cm, 90 × 20 × 7.5 cm, and 90 × 30 × 7.5 cm. The blocks also come in various sizes and are used for seed germination and transplant raising. The granular form is added to soil or used in a soilless mix; it can also be used in bags as a partial or complete substitute for peat.

The new rock wool has a pH of about 7.0–8.5, which must be corrected to about 5.5 with a slightly acid fertilizer solution before use. The exact concentration of acid required can be determined by trial and error tests on a small scale, or the necessary information can be obtained from the manufacturer. The lack of a significant cation exchange capacity in inert media makes adjusting their pH simple and inexpensive, because small amounts of chemicals are required. Before the crop is started, water the growth medium thoroughly to allow for pH adjustment, to fill the capillary tubes, and to ensure that the irrigation water added later will spread uniformly in the growth medium. For example, each litre of rock wool needs about 0.8 L of water added to fully saturate it. Its high water-holding capacity (80%) combines with adequate aeration (17%), even when fully wet.

A crop both propagated and grown in the same type of medium ensures that the capillary connections between the transplant pot and cropping media establish quickly at transplanting. Also no excessive drying out or water saturation occurs around the stems. Rock-wool blocks are available in many sizes; for cucumber propagation the most commonly used size is the 10-cm cube, individually wrapped in polyethylene to prevent excessive drying out. Raise seedlings in vermiculite or perlite and then prick them out into rock-wool blocks with a cavity at the top. Alternatively, raise seedlings by placing individual seeds into tiny rock-wool blocks (plugs), specially made to fit into the cavity of the transplant blocks, and cover them with fine vermiculite. Before using the rock-wool blocks, place them on polyethylene and wet them with an acidic nutrient solution, or better dip them into acidic nutrient solution, to adjust their pH. After pricking out the seedlings, apply nutrient solution at each watering. Use some form of bottom heat to raise the substrate temperature to 22–24°C, which is beneficial and always holds some promise for energy savings (see "Transplanting" under "General cultural practices").

When transplants are ready, stand the plants on the rock-wool slabs through precut holes on the plastic liner, and ensure good contact between the propagation blocks and the slabs. Place one or more drippers of the irrigation system on each propagation block (Fig. 15). It may also be advisable to stand the transplants on the rock-wool slabs for several days before cutting holes in the plastic liner. This procedure limits root growth to within the transplant block and slows growth by holding back water at the early stage of the spring crop, while light is limited. After the plants have established a good root system in the slabs, make slits for drainage on the sides of the plastic wrapping near the bottom of the slabs. The distance of the slits from the bottom of the rock-wool slabs determines the volume of nutrient solution on reserve and plays a major role in establishing the specifications of the irrigation system and the irrigation regime: the lower the slits, the smaller the size of the nutrient solution reservoir in each slab and the more frequent the irrigation needed. However, the lower the location of the slits, the less the volume of saturated rock wool and therefore the greater the efficiency in using the rock wool as a rooting substrate, which theoretically should result in higher productivity. Growers inexperienced in using rock wool with drip irrigation systems of modest performance should start by cutting drainage holes some distance (1–3 cm) up from the bottom of the slabs. As these growers gain experience, they could progressively extend the slits downward to maximize the use of the available rock wool.

The general guidelines on "Watering" discussed under "Peat bags" are also applicable to rock wool and must always be kept in mind (Figs. 16 and 17).

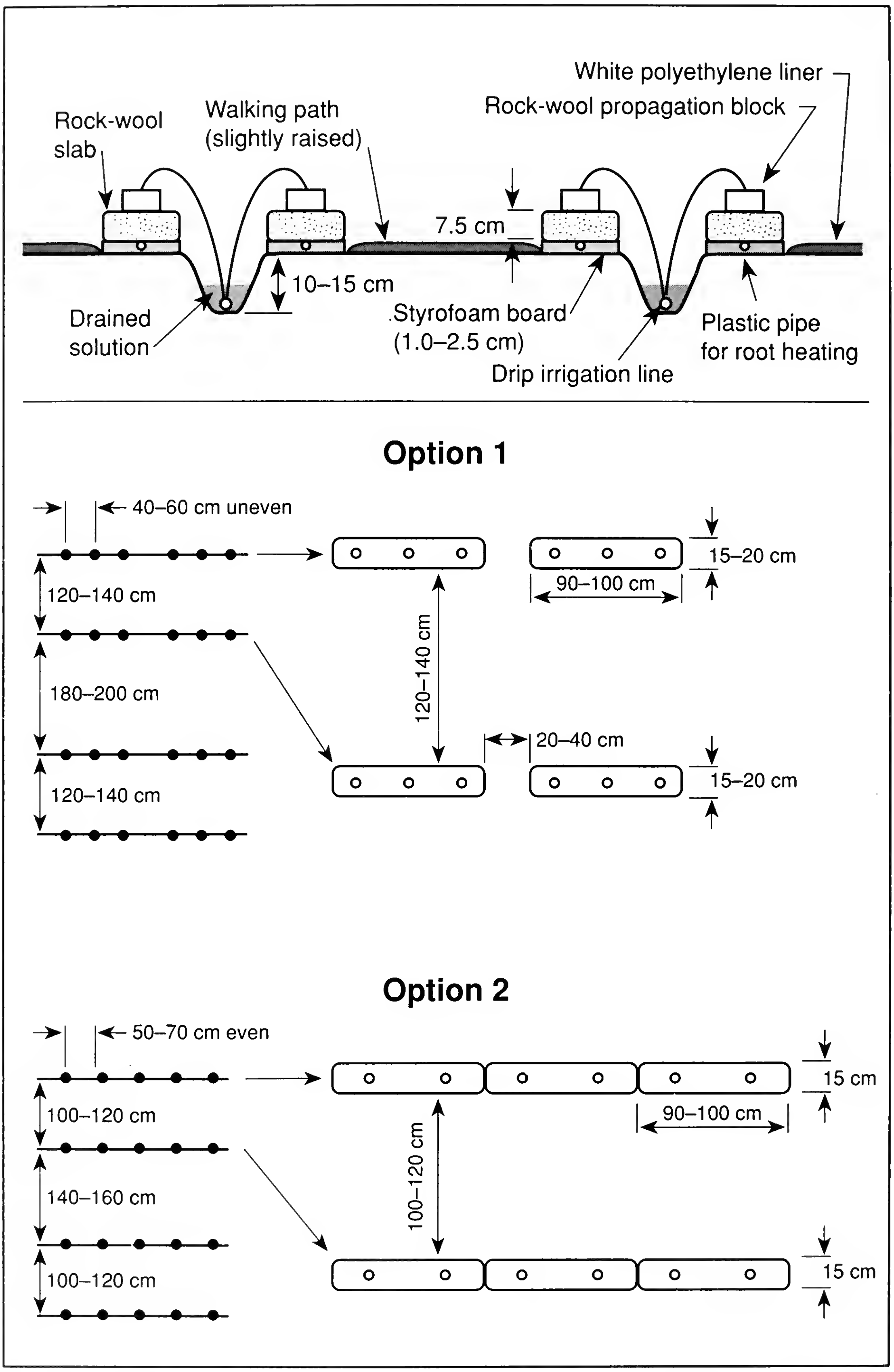

Fig. 15 Typical layout of plants for rock-wool culture. *Option 1*· Plants are trained to the canopy system giving each plant about 50 cm × 160 cm = 0.8 m^2. *Option 2:* Plants are trained to the vertical cordon system giving each plant about 60 cm × 130 cm = 0.78 m^2.

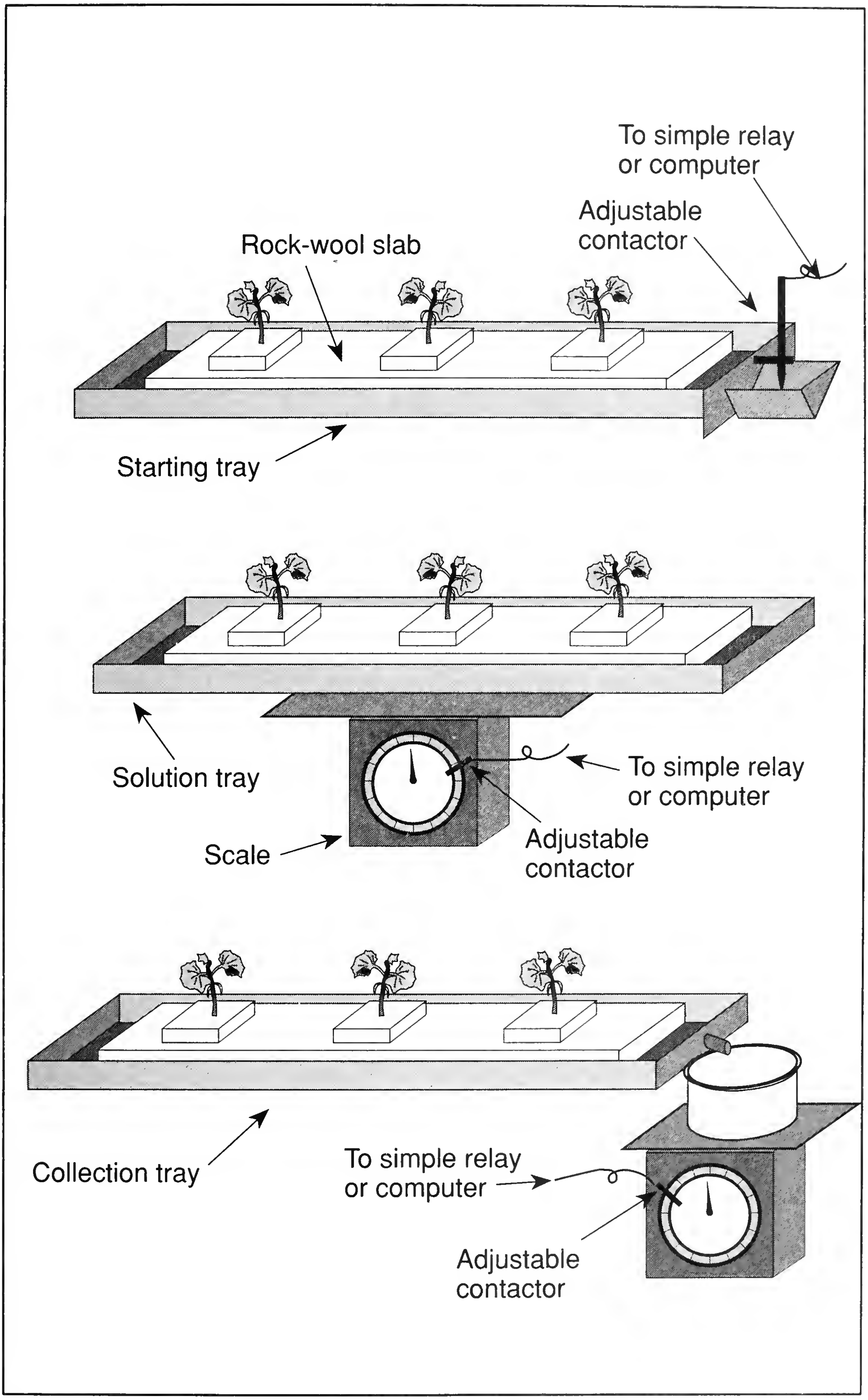

Fig. 16 Methods of irrigation control in rock-wool culture.

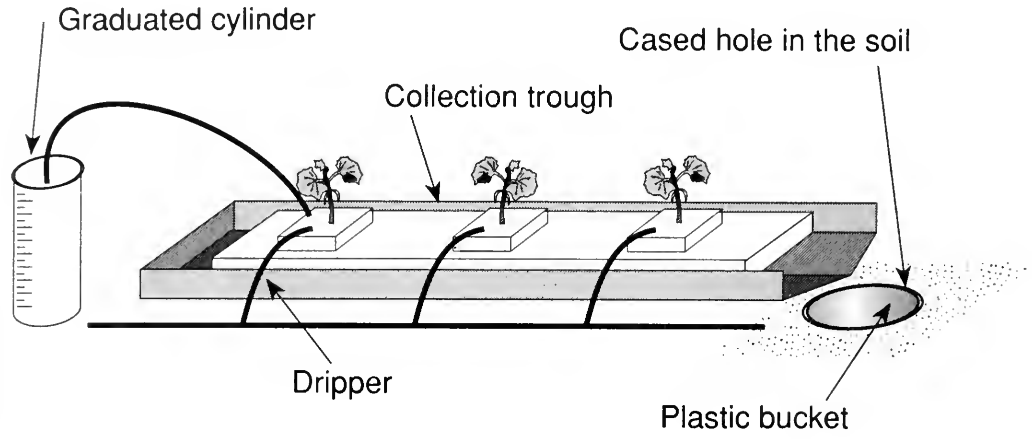

Fig. 17 Typical set up for monitoring amounts of water delivered, and leached out, per plant, in rock-wool culture.

Make the rows of rock-wool slabs as level as possible and stand them on boards of polystyrene, which help level off small imperfections in the soil surface. These boards form part of a substrate heating system, which circulates warm water through polyethylene tubing set into grooves carved in the polystyrene. The polystyrene insulates the warm rock-wool slabs from the cold soil underneath.

The nutrient composition of the fertilizer solution used in rock-wool culture depends on the chemical composition of the existing irrigation water, the stage of plant growth, and the season. Once the original water has been analyzed, calculate fertilizer and acid application rates based on the most desirable nutrient formula as determined by research and experience (Tables 26 and 26a). Always consider the quality of the irrigation water when establishing a feeding program; it is more important in rock-wool culture than in soil. For example, if the water contains a large amount of calcium or magnesium, reduce the rates of calcium nitrate and magnesium sulfate accordingly, and make up the nitrogen lost in these adjustments by increasing the amount of another nitrogen-containing fertilizer. Other nutrients, such as potassium and nitrogen, rarely occur in significant quantities in the water to require adjusting the nutrient formula. Sometimes the water supply contains a large amount of certain trace elements such as iron, zinc, and manganese. If so, the fertilizer feed needs some correction. Avoid saline water that contains more than 50 ppm sodium or 70 ppm chloride; when the concentration of these two ions reaches 100 and 140 ppm, respectively, the

Table 26 Fertigation schedule for cucumber production in rock wool

Application time	Stock A[a] (kg 1000 L^{-1}) Calcium nitrate	Potassium nitrate	Ammonium nitrate	Stock B[a] (kg 1000 L^{-1}) Monopotassium phosphate	Potassium sulfate	Magnesium sulfate	Magnesium nitrate	Recommended irrigation[b] Volume (L $plant^{-1}$ day^{-1})	EC (μS cm^{-1})
				Spring crop					
Saturation of slabs	110	32	0	17	15	33	0	5	2200
Week 1	80	46	0	13	4	25	0	0.6	1800
2	90	50	0	14	5	27	0	0.8	2000
3–4	100	50	0	16	12	33	0	1.0–2.0	2200
5–6	100	78	0	20	0	37	0	2.0–3.0	2400
7–9	95	78	3	19	0	35	0	3.0–4.0	2400
10–12	83	73	6	16	0	30	0	3.0–4.0	2200
13–19	74	66	6	14	0	14	14	3.0–4.0	2000
20–end	66	60	4	10	0	0	27	3.0–5.0	1800
				Fall crop					
Saturation of slabs	110	32	0	17	15	33	0	5	2200
Week 1	80	46	0	13	4	25	0	0.8	1800
2	90	50	0	14	5	27	0	1.2	2000
3	100	50	0	16	12	33	0	1.0–2.0	2200
4–8	95	78	3	19	0	35	0	2.0–3.0	2400
9–end	83	73	6	16	0	30	0	1.0–2.0	2200

[a] *Caution*: If fertilizers are first mixed in thick stock solutions before they are applied to the crop, group them as indicated. Do not mix in the same concentrated solution a fertilizer containing calcium and one containing sulfate or phosphate, as such a mixture results in a thick suspension that can plug watering equipment.

[b] Actual volume of irrigation water will be guided by the EC in the slab and volume of the excess solution being leached out; the EC of the slab is targeted at no higher than 20% of the EC of the applied solution, and, the volume leached at no more than 20–30% of the solution applied.

Notes:

- Trace elements must also be added to all the above fertilizer feeds; a typical trace element mix (e.g., Plant Product Chelated Micronutrient mix) contains 7.0% Fe, 2.0% Mn, 0.4% Zn, 0.1% Cu, 1.3% B, and 0.06% Mo; when added to the stock solution at the rate of 1 kg 1000 L^{-1} it contributes to the final solution 0.7 ppm Fe, 0.2 ppm Mn, 0.04 ppm Zn, 0.01 ppm Cu, 0.13 ppm B, and 0.006 ppm Mo, with a 1:100 dilution ratio.
- Dissolve given amount of each fertilizer, including trace elements, in 1000 L of water and add to the irrigation water in equal doses, ideally with a multihead fertilizer injector. Start injecting very slowly and increase the rate of injection progressively, and uniformly on all heads, until the desired EC is achieved. Adjust the pH of the fertigation solution to 5.5 by injecting a dilute solution of phosphoric, nitric, or sulfuric acid. Alternatively, dissolve the prescribed fertilizers, including the micronutrient mix, into 100 000 L of water, adjust the pH, and apply directly to the crop.
- The recommended strength of the stock solutions is within the working range of a fertilizer injector with a 1:100 mixing ratio. If a fertilizer injector with a 1:200 mixing ratio is used, double the amount of each fertilizer. Similar adjustments can be made for fertilizer injectors with other mixing ratios. If the solubility limit of a fertilizer (e.g., potassium nitrate) is exceeded, prepare more than one stock solution of the same fertilizer and divide the amount of the fertilizer equally between the stocks.

Table 26a Nutrient concentration in the final nutrient solution when one part of each of stock solutions A and B, prepared as described in Table 26, are mixed with 98 parts of water (i.e., 1:100 dilution ratio)

Application time	Nutrient (ppm)												EC[a] ($\mu S\ cm^{-1}$)
	$N\text{-}NO_3$	$N\text{-}NH_4$	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	
						Spring crop							
Saturation of slabs	201	11	39	231	209	33	1.4	0.4	0.08	0.26	0.02	0.012	2200
Week 1	176	8	29	228	152	25	1.4	0.4	0.08	0.26	0.02	0.012	1800
2	195	9	32	250	171	27	1.4	0.4	0.08	0.26	0.02	0.012	2000
3–4	210	10	37	284	190	33	1.4	0.4	0.08	0.26	0.02	0.012	2200
5–6	246	10	46	353	190	37	1.4	0.4	0.08	0.26	0.02	0.012	2400
7–9	244	15	44	350	180	35	1.4	0.4	0.08	0.26	0.02	0.012	2400
10–12	226	18	37	323	158	30	1.4	0.4	0.08	0.26	0.02	0.012	2200
13–19	230	17	32	291	141	27	1.4	0.4	0.08	0.26	0.02	0.012	2000
23–end	211	13	23	256	125	24	1.4	0.4	0.08	0.26	0.02	0.012	1800
						Fall crop							
Saturation of slabs	201	11	39	231	209	33	1.4	0.4	0.08	0.26	0.02	0.012	2200
Week 1	176	8	29	228	152	25	1.4	0.4	0.08	0.26	0.02	0.012	1800
2	195	9	32	250	171	27	1.4	0.4	0.08	0.26	0.02	0.012	2000
3	210	10	37	284	190	33	1.4	0.4	0.08	0.26	0.02	0.012	2200
4–8	244	15	44	350	180	35	1.4	0.4	0.08	0.26	0.02	0.012	2400
9–end	226	18	37	323	158	30	1.4	0.4	0.08	0.26	0.02	0.012	2200

[a] The EC of the water has been assumed at zero (i.e., rain water).

Note: The ideal micronutrient concentrations (ppm) in the final solution are 0.6–1.2 Fe, 0.3–0.6 Mn, 0.2–0.7 Zn, 0.4–0.7 B, 0.02–0.07 Cu, and 0.01–0.02 Mo.

water cannot be used easily in rock-wool culture. When using rainwater, raise the usually low level of bicarbonate by adding potassium bicarbonate to the final solution, not to the stock solutions, to increase the buffering capacity of the solution for a more stable pH in the rock-wool slabs. On the other hand, when the bicarbonate in the water supply exceeds 60 ppm, add phosphoric or nitric acid (or both) to neutralize it. For a proper solution to these special problems, seek a second opinion, preferably that of a horticultural adviser or of an experienced grower.

Although rock-wool systems function well with either recirculating or nonrecirculating nutrient solutions, the use of the latter system is simpler and more reliable. However, even a nonrecirculating, open-ended system needs checking and repairing regularly. Check the pH and electrical conductivity (EC) of the solution daily, given the inert nature of the substrate and the quick response of the crop to human error and mechanical failure. A recirculated system (Fig. 18) results in less fertilizer run-off into the environment and, in the future, its use might become mandatory.

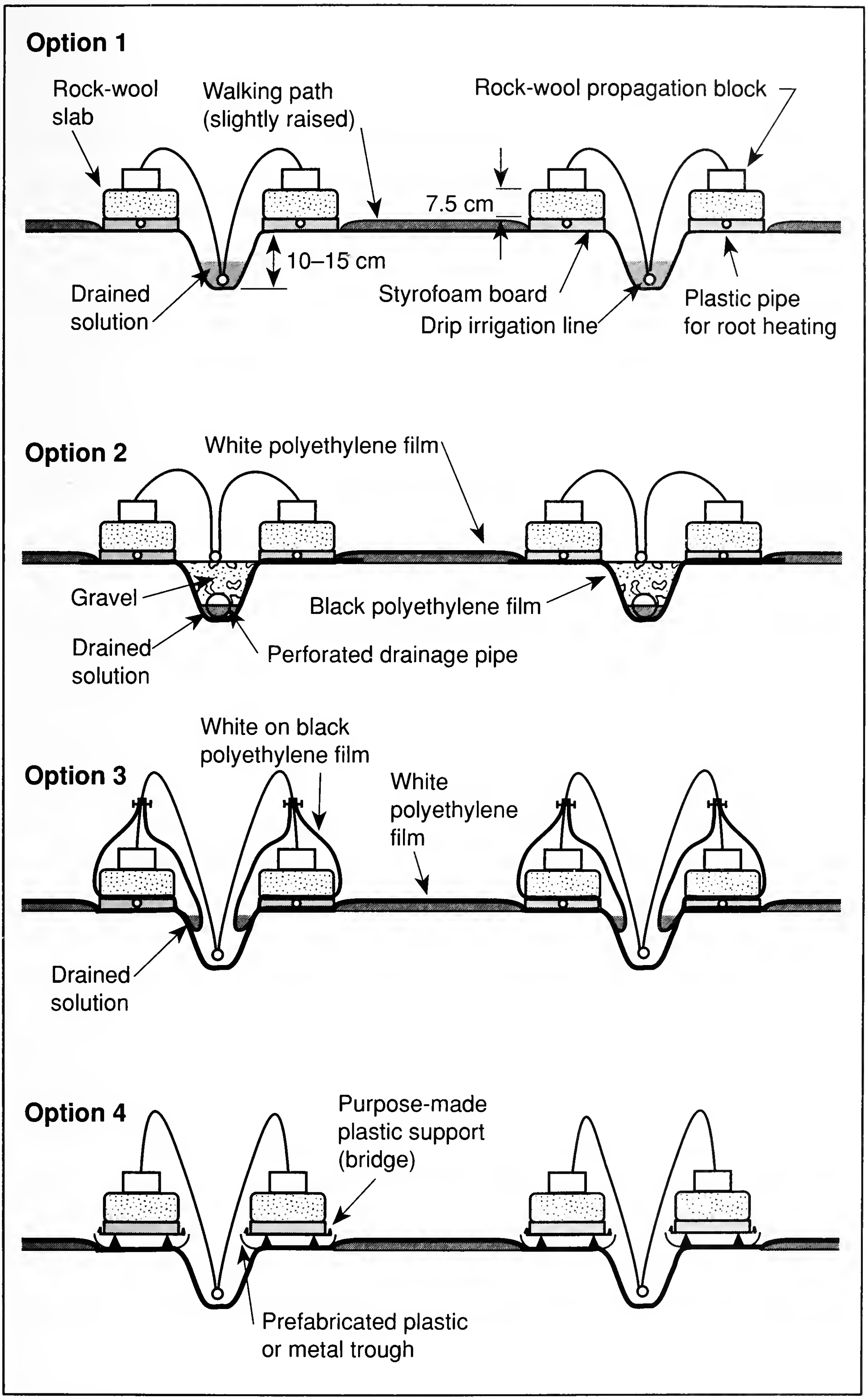

Fig. 18 Methods of nutrient solution recycling in rock-wool culture.

Make up at least two stock solutions from readily available fertilizers, to avoid precipitation in the concentrate storage tank that results from the mixing of calcium- or magnesium-containing fertilizers with those containing sulfates or phosphates. Dilute the stock solutions and combine them in a mixing tank before applying them to the crop, thus providing a complete nutrient solution at every watering. Monitor the total concentration of nutrients in the irrigation water continually by a salt sensor (electrical conductivity cell) and, if necessary, adjust the mixing ratio of the fertilizer diluter to achieve an optimum feeding strength for the crop; automatic adjustment is technically available. Similarly, monitor, with a pH meter, the pH of the irrigation water after adding all fertilizers and any acid. Adjust the rate of acid application to achieve a desirable pH for the nutrient solution; automatic adjustment is technically available. Choose from many alternative feed recipes, depending on the cultivar grown, the water source, the stage of crop growth, and the season. The fertigation recommendations in Tables 26 and 26a rely on using rainwater. Treat them only as a starting point in the search for finding the optimum for a given operation.

Check daily the pH and salt concentration (EC) of the slab solution, and run an analysis every 2 weeks for all essential nutrients. Correct serious nutrient imbalances by making appropriate changes to the nutrient formula, but the changes should deviate as little as possible from the normal solution. Have an experienced person double-check the contemplated changes to the nutrient feed before implementation; then implement them only until the imbalance is corrected. Changes in the nutrient formula based on crop growth and appearance are also possible, but allow only persons with experience in rock-wool culture to make such changes. To reduce costs, use rock-wool slabs for more than one season, provided they get effectively steam-sterilized in between crops. Thoroughly flush out accumulated salts with plain water for 1–2 h before sterilization. Methyl bromide, if available, can also function to sterilize rock wool between crops, but steaming is more effective over a greater variety of pathogens and is preferred when available. **Recommended fumigants, their use, and rates of application are subject to government regulations, which can vary from province to province. Licensing is required before certain fumigants (e.g., methyl bromide) can be used. Pay strict attention to regulations governing fumigant use and take precautions during application.** After sterilizing the slabs, rewrap them with polyethylene film so that they are ready again for use. Reused slabs require no further pH adjustment and are easier to rewet than new ones. Rock-wool slabs can be reused only a limited number of times, usually once. Some breakdown in their fiber structure occurs with handling and sterilization, and as a result the air pore space in the slabs decreases with every reuse. An interesting alternative to the reuse of rock-wool slabs for reducing production cost is the recently introduced low-density, low-cost rock-wool slab that is used for a single cropping season.

The ideal micronutrient concentrations in the final solution are 0.6–1.2 ppm Fe, 0.3–0.6 ppm Mn, 0.2–0.7 ppm Zn, 0.4–0.7 ppm B, 0.02–0.07 ppm Cu, and 0.01–0.02 ppm Mo.

Perlite

Perlite is volcanic glass. When this rock is crushed and heated (to about 1000°C), the small quantity of water trapped in it vaporises and puffs out the granules (just like popcorn) to form white foamy beads. This product was used initially in the construction industry for insulation and the preparation of light weight building components. The grain size of horticultural-grade perlite ranges between 1 and 5 mm. Expanded perlite is light, physically stable, and chemically inert; it holds large quantities of readily available water, has a strong capillary attraction to water, and, because it drains easily, is also well aerated (Table 2). The material has a closed cellular structure, and therefore most of the water retained after drainage is held superficially.

Two primary sources of perlite are the island of Milos in Greece and the island of Sardinia in Italy. Although perlite has been used extensively worldwide in soil and peat mixes for plant raising, its use as a substrate for soilless production of cucumbers received particular attention in Scotland, Greece, and other European countries. The cropping techniques and fertilizer application schedules have been described in specialized publications. Crop growth and productivity, which have been reported as encouraging, compete with those of the widely used rock wool.

Containers of various shapes and sizes can be used for holding the growth medium. Most commonly used are large pots, upright plastic bags, troughs (similar to those used for peat, Fig. 14), and bolster bags of various sizes. Extensive studies, reports, and practical experience exist on the bag- and gulley-reservoir methods pioneered in Scotland.

The bag-reservoir method is based on 30-L polyethylene growing bags (bolsters) filled with perlite and supporting three plants each. Its key feature is that horizontal slits are cut at about 3–4 cm up from the base of the bag. In this open system, any excess nutrient solution applied collects to a depth of 3–4 cm in the bottom of the perlite in each bag. Aided by the high capillary action of perlite, this reservoir ensures an uninterrupted water supply to the plants with just a few irrigations per day and without placing a high demand on the irrigation system for uniform water delivery. European recommendations for the nutrient concentration of the main season feed of cucumbers grown in perlite call for 190 ppm N, 42 ppm P, 260 ppm K, 145 ppm Ca, 35 ppm Mg, 2 ppm Fe, 0.75 ppm Mn, 0.5 ppm Zn, 0.4 ppm B, 0.1 ppm Cu, and 0.05 ppm Mo.

The gulley-reservoir system is a closed system better suited to nutrient recirculation. The distinguishing feature of this system is the use of an extra sheet of plastic wrapped around the growing bags. This plastic maintains an even larger reservoir of nutrient solution or even allows for subirrigation to be practiced when the greenhouse floor is

reasonably level. The same schedule used for applying fertilizer to cucumbers grown in rock wool is believed applicable to cucumber production in perlite. However, interested growers should proceed cautiously because there is little experience with this approach in Canada.

Vermiculite

Vermiculite, a hydrated magnesium aluminium silicate, appears in nature as platelike crystals. Large deposits of this mineral occur in the United States, South Africa, and elsewhere. When heated appropriately, the water trapped in it vaporizes and causes the mineral to exfoliate (puff-out). The exfoliated vermiculite is a lightweight material of alkaline reaction, with high cation-exchange and water-holding capacities. Because of these qualities, vermiculite has become a popular ingredient in soil and peat-based mixes for plant production.

Vermiculite is rarely used as growth substrate by itself. When price permits, it can be used to fill troughs, bags, or pots for growing cucumbers. The general cultural technique described for peat and the fertilizer application schedule recommended for rock-wool culture can serve as a basis in developing an appropriate strategy for crop management.

The main reasons for the limited use of vermiculite as a substrate for cucumber production are its initial alkaline reaction and its tendency to collapse over time. Structural collapse leads to reduced aeration and drainage.

Oasis® and other synthetics

Synthetic organic materials, such as expanded polystyrene, urea-formaldehyde, and polyurethane foams, are inert. With proper treatment, they form useful substrates for cucumber production. Some of these materials are available as slabs (e.g., polyurethane foam) and have been used commercially in a manner similar to rock wool. Other materials come in granular form (e.g., Oasis®) and have been used in place of the peat-mix in peat-bag culture.

Oasis®, a phenolic-based foam, has stable structure, high porosity (97–98%), good aeration, high water-holding capacity, light weight, and acidic pH. It is available in block form, for transplant raising, and in granular form, for filling bags; it is not readily available as a slab. The plastic bags used to contain oasis have been narrower than the peat-bags (typically about 15 cm in diameter) and their length has varied between 80 and 120 cm. With two or three plants grown in each bag, the volume of substrate available to each plant has been on the low side (e.g., 7 L), but results have been satisfactory even when the same material was used for several crops (i.e., with proper sterilization of the medium in between crops).

Because the pH of new Oasis® is on the acid side (well below 7), use an alkaline solution, usually of potassium bicarbonate in water at 1 g L^{-1}, to

soak the material for 24 h before slitting the bags. Then cut horizontal drainage slits at about 2–3 cm from the base. Once the bags have drained, planting, drip irrigation, fertigation, and all other cultural practices resemble those described for peat bags and rock wool. No specific schedule for fertilizer application has been described, but the recommendations for rock-wool–grown crops should also apply to this medium.

Expanded clay

Expanded clay pellets, like rock wool, were initially designed as insulating building material. They are produced by baking clay at 1100°C at which temperature it expands into porous granules. The granules have been marketed at various sizes for different horticultural uses. Intact granules have a closed-cell structure; their low water-holding capacity, fast drainage, and high aeration make them an attractive medium for closed (recirculated) systems and for systems using subirrigation. Crushing the granules exposes the porous material, and the water-holding capacity of the medium increases significantly. Commercial systems use large, drained pots to contain the medium, and drip irrigation for fertigation (Plate IV*e*); rapid percolation makes spray nozzles preferable to drippers. Some growers use plastic troughs to collect excess nutrient solution, but the management of a cucumber crop with nutrient solution recycling requires some skill.

Following management practices and the fertilizer application schedule for rock-wool, crop performance in clay pellets, used as an open system, has been very satisfactory. The stable structure of the clay granules, especially when intact, ensures the long-term use of the medium over several seasons, provided that you sterilize it effectively between crops.

Sand and gravel

Other nearly inert media such as sand and gravel have also been used as growing substrates for greenhouse vegetables. Information on sand and gravel culture comes mostly from other countries; a few Canadian growers have experimented with them. These media are heavy, difficult to handle, difficult to sterilize between crops, and usually require extensive and permanent modifications to the greenhouse floor. Like most other media, sand and gravel have an equally high yield potential when managed properly and can prove the best choice under certain conditions.

Nutrient film technique and other hydroponic systems

WARNING: The NFT system is not recommended for long-term cucumber crops because of frequent, and unresolved, crop losses from widespread root death; consult your local horticultural crop adviser before using NFT (Plate IV*f*).

Of all the soilless methods, water culture, by definition, is a true hydroponic system. The nutrient film technique (NFT) is a relatively new water-culture system based on the simple principle of circulating a shallow stream, or film, of nutrient solution over the roots of growing plants to provide an adequate supply of water, nutrients, and oxygen (Fig. 19). The concept of the nutrient film is credited to A.J. Cooper, who while at the Glasshouse Crops Research Institute in Littlehampton, England, recognized its value and called international attention to its commercial potential as early as 1973. Since then, NFT has undergone intensive testing by scientists and commercial growers in many countries,

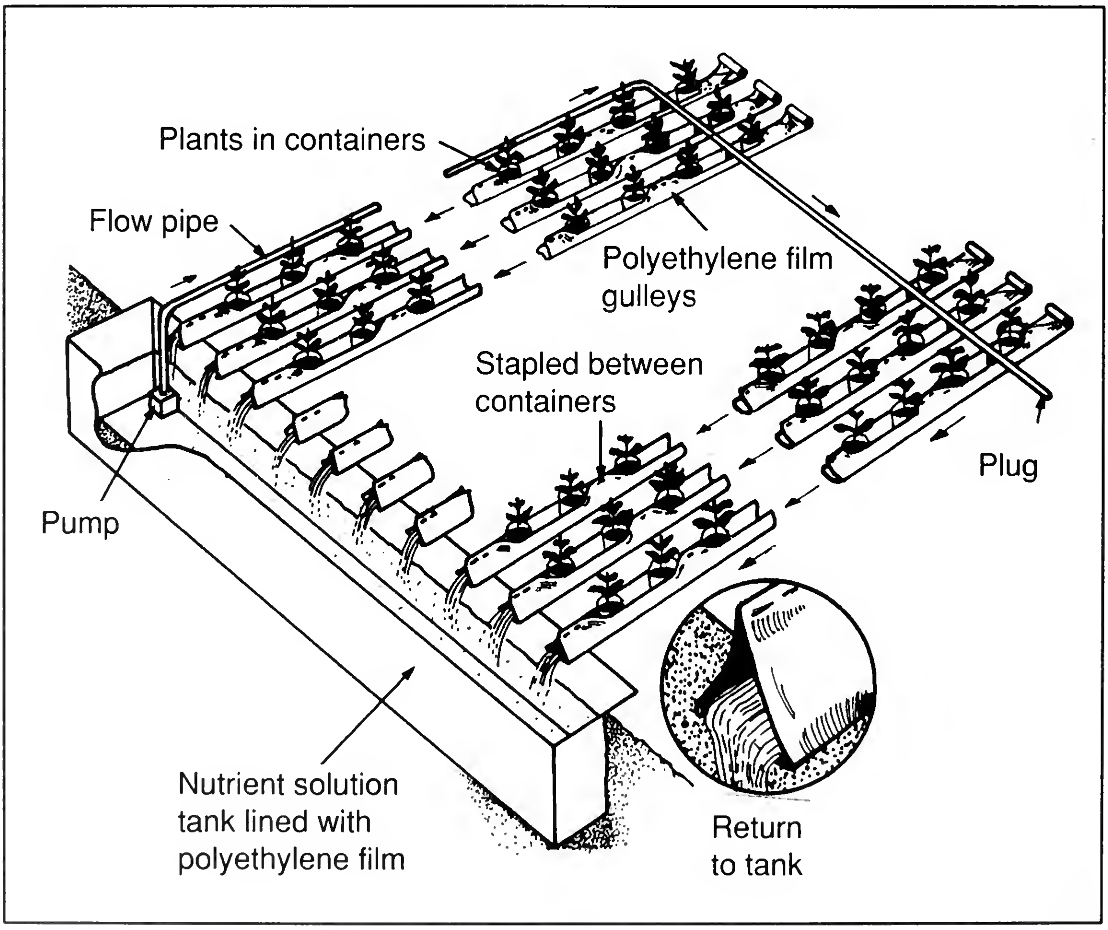

Fig. 19 The concept of NFT.

including Canada, and is now considered a commercially viable form of water culture for several crops, but not cucumbers.

Fig. 20 illustrates the general layout of an NFT installation, with its various components. Although many versions of NFT are in current use, the basic components of a typical NFT installation are as follows:

- Parallel gullies, or troughs, in which to grow the plants are laid on a 1–2% slope, on which the nutrient solution flows. Originally, producers grew the plants with their roots in lay-flat tubing, but this method failed to provide maximum aeration of the roots. Later, they used gullies made from a strip of polyethylene folded lengthwise (Fig. 21). The gullies may also be prefabricated from semirigid plastic.
- A catchment tank contains nutrient solution where fertilizers, water, and acid are added.
- A circulation pump draws solution from the catchment tank and delivers it to the upper ends of the gullies.
- A catchment pipe collects solution discharged from the gullies.
- Fertilizer and acid supply tanks store concentrated fertilizer stock solutions and an acid solution.

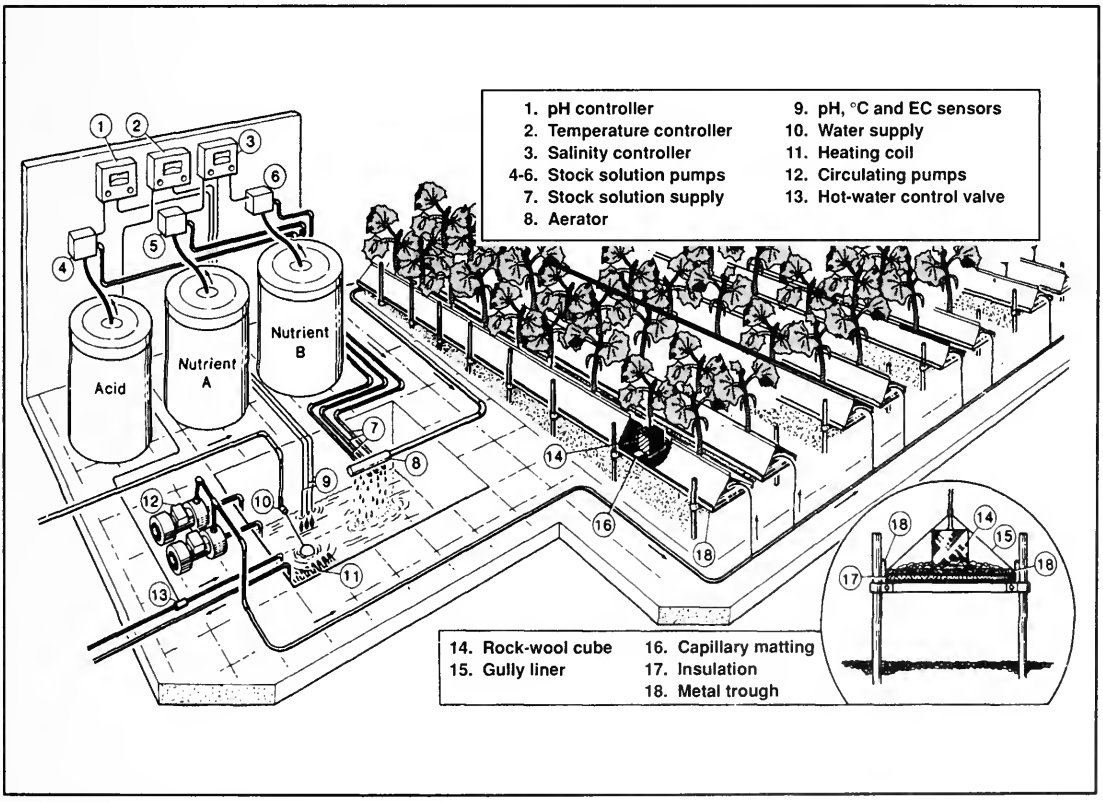

Fig. 20 A typical NFT installation.

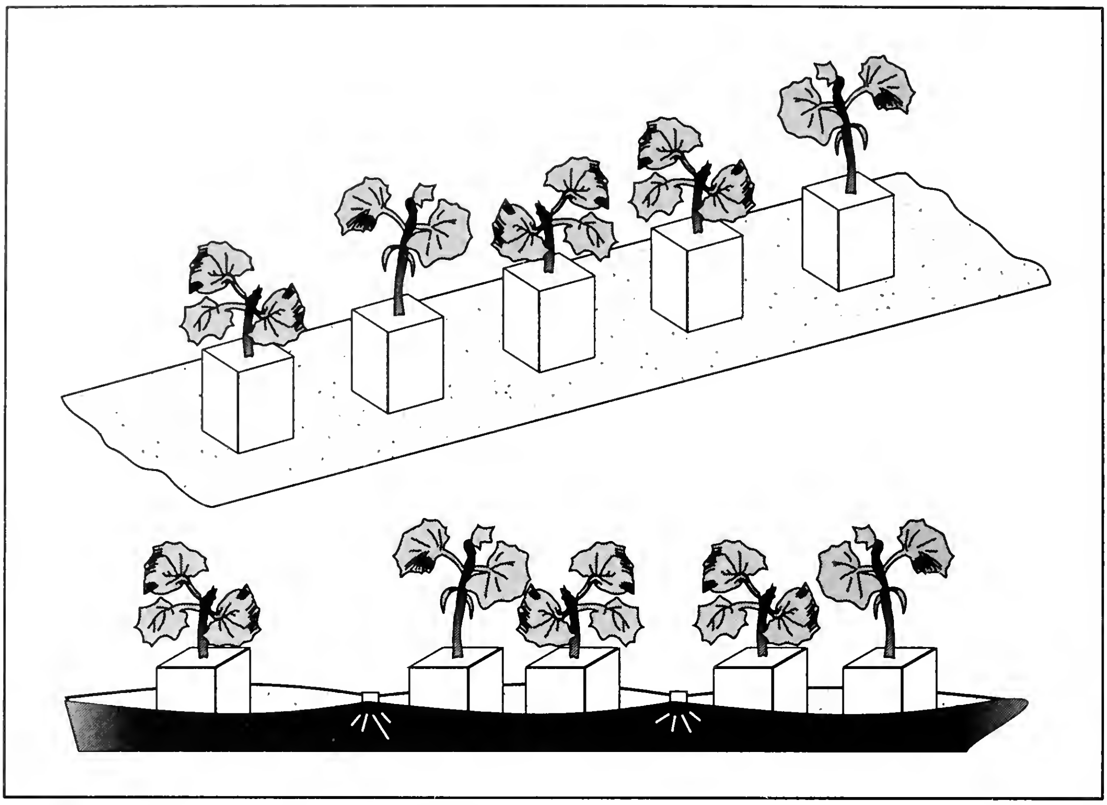

Fig. 21 Gully construction for NFT.

• Monitoring and control equipment maintain nutrient concentrations (including total amount of salts), pH, and water level. An electrical conductivity (EC) controller and a pH controller are commonly used to regulate the operation of dosimetric pumps or solenoid valves. These pumps, or valves, control the transfer of fertilizers and acid to the catchment tank. A mechanical floating valve or a variety of electronic controls easily maintain a constant water level in the catchment tank.

NFT has many advantages over other systems of crop production. It has been designed for simplicity, low cost, and dependability. In particular, it gives absolute control of the root environment; it greatly simplifies watering, and ensures a uniform nutrient supply across the whole crop. Root temperature can be raised easily whenever required merely by warming the nutrient solution, which can be circulated either continuously or intermittently to further conserve energy and to control the vegetative growth of young winter-grown plants.

Other advantages include a rapid turnaround between successive crops, the potential for more efficient use of greenhouse space because of the possibility of plant mobility, and the potential for more efficient use of water. NFT's high degree of control over nutrition, water availability, and root environment makes it the most sophisticated of all commercial plant-culture systems in practice today. Theoretically it offers the highest yield potential.

However, many of the advantages of NFT are also offered, to some degree, by other soilless methods, notably rock wool. Much scepticism therefore persists about the future of NFT, because it is generally perceived as a technique that requires a high level of technical skill. Growers have some concern about the possibility that the recirculating nutrient solution may amplify and spread diseases in the system, resulting in disastrous crop losses. Unexplainable outbreaks of root death have repeatedly occurred, which have fueled concern over potential spread of diseases in NFT cucumbers.

The NFT method, the deep-culture technique (pioneered in Japan), and other closed-loop hydroponic methods are now being reexamined with renewed interest because of their potential for minimizing fertilizer waste and environmental pollution.

NFT was originally developed as a low-cost system using lightweight, disposable gullies and simple salinity and pH controllers. However, as the system became a commercial reality, it became inceasingly automated, standardized, and sophisticated, which made the capital cost of the initial installation a major concern for growers contemplating its use. Fortunately, the original simple and low-cost NFT system is nearly as good as the high-cost ready-to-use ones in the international market. It still offers the best opportunity to the average grower who would like to try NFT on a small scale without risking great losses. Many publications now describe the NFT technique in great detail. Also, several Canadian companies are offering turn-key operations or are well stocked with all NFT-related instruments and supplies.

The following summary gives some general rules and recommendations for NFT use, for the benefit of those who may not have access to more-detailed, specialized publications. It emphasizes particularly aspects of NFT that proved problematic during its development.

Make the base of the gullies about 25–30 cm wide. A maximum length of 20 m works well for gullies set on a nominal 1% slope; longer gullies can be used for the nutrient solution, but with higher slopes or with several introduction points along the length of the gullies. For constructing the gullies, especially for the fall crop, use coextruded polyethylene film (white on black) 0.1 mm thick, when available. Lay the plastic film (a strip about 75 cm wide) in position, black side uppermost, on the prepared supporting surface (e.g., polystyrene sheets on graded soil or elevated tray-supports manufactured from galvanized metal and other materials); raise the sides and staple them together between the plants to form a gully of triangular cross section (Fig. 21). The inside black surface of the plastic serves to keep the light out of the gully, which prevents algae from growing in the nutrient solution. The white outside surface of the plastic reflects the incoming light, which enhances plant growth and prevents the plastic from getting too hot. Overheated plastic gullies have burned the stems of transplants started in the summer. A thin plastic film, as recommended previously, is preferred over a thicker film. Wrinkles in the former help to disperse the nutrient solution while a

crop becomes established and until enough roots grow outside the propagation blocks.

Various approaches have been tried to prevent young transplants from drying out during the first few days after transplanting. For a simple and effective solution to the problem, place the transplants on a narrow strip of capillary matting at planting time. A second set of crop-supporting wires are usually necessary at a low level to help lay down a crop without moving the plastic gullies out of place, which can lead to serious losses of nutrient solution. Transfer the nutrient solution from the supply line into the gullies through at least two small-bore (2–3 mm inside diameter) flexible tubes, to guard against blockage. Of the NFT components that come in contact with the nutrient solution, have as many as possible made of plastic because metal can release potentially toxic levels of certain micronutrients, such as zinc and copper, into the solution.

Because of the widespread use of plastics, select only materials that are not phytotoxic. As a general recommendation, PVC and low- and high-density polyethylene or polypropylene are acceptable, but do not use plasticized PVC (used in the manufacture of flexible hose) or butyl rubber sheet lining (used for waterproofing reservoirs) in NFT because they may be phytotoxic. Plastics are more likely to cause phytotoxicity when new. Plastic surfaces quickly lose their potential phytotoxicity when exposed to nutrient solution. Therefore, before planting a crop, flush out the new hydroponic installation entirely for 1 day with a dilute nutrient solution that is then discarded.

To ensure good root aeration, allow an adequate rate of flow in the gullies (e.g., 2 L min^{-1}) and a depth of solution of no more than 1 cm, even when the root mat is well developed. To provide a suitable slope, grade the surface carefully before laying the gullies to avoid localized areas of deeper, stagnant solution. In planning the layout, take advantage of any natural slopes in the greenhouse. A second slope at right angles to the flow in the gullies facilitates the return flow to the main (catchment) tank, which is most conveniently located at the lowest corner of the greenhouse complex. Although NFT at first relied on sloping soil surfaces, occasionally made of concrete, an increased interest is now evident in raised systems using rigid platforms, which support the gullies, and in adjustable stands. Such systems eliminate pockets of deeper solution resulting from poor soil leveling and allow for slope adjustment, even during cropping. Furthermore, a raised NFT system can be installed and operated in an old greenhouse, where grading the soil might be difficult or even impossible. Widely available fiber glass or plastic containers have been used as catchment tanks, but because they are usually small their usefulness is limited to small NFT installations. For larger installations, deep holes or pits in the soil lined with polyethylene film are sometimes used. Avoid this system, however, because the film often develops leaks and can create other problems. A pit-liner made of polyethylene film reinforced with fiber glass or nylon fiber is a much better alternative.

A concrete tank, properly sealed with resin, or a tank prefabricated in plastic with external reinforcement, makes an excellent choice for a permanent catchment tank in most NFT installations. Cover the tank to exclude light, to prevent algae growth, and to limit contamination of the solution by soil organisms. Adequately insulate the catchment tank to prevent the solution from becoming too cold and to conserve energy when the nutrient solution is heated. An NFT system that supports 1 ha of mature vine crop contains about 50 m^3 of nutrient solution, of which only 5–8 m^3 is in the catchment tank; the rest circulates in the gullies. When designing an NFT system, allow a minimum catchment tank capacity of 10 m^3 for every hectare of greenhouse area; if you contemplate using an intermittent flow of nutrient solution, you will need to increase the capacity substantially. Although larger tanks would increase the nutrient supply and pH stability of the system, consider the tank's cost-to-benefit ratio also before you make your final decision. Like all aspects of NFT, the design of catchment tanks is still being developed, with the objective of improving mixing and aeration of the nutrient solution and ensuring optimum pH and EC control.

Various techniques have been developed to further increase oxygenation of the nutrient solution. Two separate return pipes can be arranged to enter the catchment tank at right angles to each other so that the nutrient solution streams converge well above the solution in the tank. Also, instead of discharging the nutrient solution into the catchment tank through an open-ended pipe, a tee or other pipe modifications can be used to encourage dispersion. A more deliberate attempt to increase mixing and aeration of the nutrient solution in the catchment tank involves the direct return, under pressure, of some of the nutrient solution pumped by the main circulation pump. As with every component in contact with the nutrient solution, ensure that the main pump can handle corrosive solutions; therefore use stainless steel or plastic-bodied pumps. Self-priming pumps are preferable, but avoid the submersible types because they eventually corrode and can fail. By using several smaller pumps instead of a single large one, the solution continues to flow even when one pump fails. Also, a pressure-sensitive switch can activate a spare pump if the main one fails and the pressure in the system drops. To guard against total power failure, a stand-by generator is essential for large installations and for areas that experience frequent and extended blackouts. A small operator might avoid the extra cost of a stand-by generator by connecting the main water supply through a one-way valve to the NFT system. Then at least the crop receives plain water during a power interruption; but providing appropriate drainage is essential in this case. View this approach, however, only as an added safety feature built into the NFT system rather than as a first line of defence against power and pump failures.

Supply the catchment tank with an overflow of at least the same capacity as the maximum rate of the nutrient solution being returned from the crop to the catchment tank. Although providing an overflow might seem expensive and complicated, it is absolutely necessary as a last

resort to avoid disastrous floodings when all other safety measures to keep the nutrient solution flowing fail.

Fertilizers and acid are normally added into the catchment tank in the form of concentrated stock solutions. The dosimetric pumps used to inject nutrients and acids into the catchment tank should be chemically resistant—at least in those parts that come in contact with the relatively concentrated solutions. Use two pumps for fertilizer and one for acid; their size depends on the size of the operation, but most growers need an average capacity of 10 L h^{-1}. The two nutrient pumps used for fertilizer injection should be adjustable so that they can be set to deliver exactly the same volume of liquid. Regulate the operation of the fertilizer and acid injection pumps by their respective controllers. In large installations it may be more economical to replace the dosimetric pumps with solenoid valves that control the gravity-driven flow of stock solutions. Several suppliers now have available complete nutrient and acid dosing sets in ready-to-use packages. However, growers can easily assemble tailor-made systems that suit individual needs because most of the needed components are widely available.

Salinity and pH controllers are also required. A salinity controller provides the best method for determining the salt concentration by measuring and controlling the electrical conductivity (EC) of the solution. This method uses the principle that the electricity conducted between two electrodes, immersed at a fixed distance (usually 1 cm) in a solution, is proportional to the total ionic (salt) concentration in that solution. The EC controller monitors and displays the conductivity of the nutrient solution and activates the metering (dosimetric) pumps when the measured conductivity falls below a preset value and only until the measured value regains the preset value. Electrical conductivity is usually reported in either microSiemens per centimetre (μS cm^{-1}) or micromho per centimetre (μmho cm^{-1}). Other units and conventions are used occasionally to express EC, but the relationships between them are straightforward: for example, 1 milliSiemen (mS) = 1 millimho (mmho) = 1000 microSiemens (μS) = 1000 micromho (μmho) = 10 conductivity factor (CF) units; reference to centimetres is usually omitted, but implied. The cells (sensors) used in conductivity measurements are encased in plastic, which makes them sturdy, requiring only minimal maintenance.

Two main types of conductivity cells are available: a dip cell suspended in the solution and suitable for small installations, and a flow-through type cell incorporated in the pipeline. In the latter case a sampling loop returns some of the main circulating pump's output solution directly back into the catchment tank after it has passed through the conductivity cell. The electrical conductivity of a solution increases by about 2% for every degree Celsius that the temperature increases. Therefore equip the conductivity controller with automatic temperature compensation—a standard option in most conductivity controllers. A general recommendation for the optimum conductivity setting on the salinity controller is difficult to provide because the setting varies according to the cultivar grown, the season, the stage of growth, and the

quality of the water. First measure the electrical conductivity of the water (assume an x reading is obtained) and then set the salinity controller at $x + 1500$ μS. A balanced nutrient solution suitable for the growth of most plants has a conductivity of about 1500 μS. Where the water supply contains nutrients in excess of plant requirements, or where the fertilizers are not supplied in a ratio proportional to nutrient uptake by the crop, a buildup of certain nutrients inevitably results. Nutrients that can accumulate over time include calcium (from hard water), sulfate (from fertilizers), sodium and chloride (from saline water), and possibly others. Under these conditions the background conductivity rises progressively, so proportionate increases in the EC setting of the salinity controller are needed to maintain an adequate nutrient supply. Unfortunately, no simple and practical procedure exists to determine the changes in background conductivity. Therefore discard the nutrient solution periodically and add new solution into the system.

The frequency at which to renew the nutrient solution depends on the stage of crop growth and the season, both of which affect the rate of nutrient and water uptake by the crop. Generally, renew the solution every month at the beginning of a crop and twice a month later, when the crop is fully grown or whenever the crop appears to have stopped growing. As the grower gains experience with the system, the solution may need less frequent renewal.

While the NFT operation is being established, weekly chemical analysis of the nutrient solution is essential for crop safety and for familiarizing the grower with the operation; as the grower gains experience, less frequent analysis can be conducted, e.g., twice a month. The pH of the nutrient solution also influences considerably crop growth, and therefore it is monitored and controlled continually within the range of 5.5–6.5. Avoid values below 5; a pH below 4 damages most crops. At the other end of the pH range, the availability of trace, or minor, elements (except molybdenum) decreases when the pH rises above about 6.5, establishing the upper limit of a desirable pH level in the solution. Where the main source of nitrogen is nitrate or where the pH of the water is high (>7.0), the pH of the solution rises during cropping; a control system consists of a pH monitor-controller and a metering pump that adds an acid, usually phosphoric or nitric. However, when a significant portion of the nitrogen is supplied as ammonia and the buffering capacity of the water is low, the pH can drop below the lowest value acceptable and a base, such as sodium hydroxide, may have to be added to raise the pH to within the acceptable range. Dilute the concentrated acids as purchased at a ratio of 1 : 10 or preferably 1 : 20 before use; the exact concentration required varies according to the capacity of the metering pump or solenoid and the size of the catchment tank. For large installations seek the advice of a chemical engineer who specializes in designing the proper storage and handling procedures for dangerous chemicals.

WARNING: Both acids and bases can cause serious burns to workers if handled carelessly; always wear protective clothing, masks, and glasses when handling these chemicals. When diluting concentrated chemicals, always add the acid or base to the water; never add water to a concentrated acid or base because the solution could get overheated and explode, causing serious burns.

A great variety of safety devices and precautions are available to guard against failure of the pH and salinity controllers. Timers are routinely installed that can override either of the two controllers and prevent the continuous addition of fertilizer or acid to the solution for periods that exceed a normal, expected time span. Also, small tanks for the stock and acid solutions can be used, so that the crop would not be damaged, even if all their contents were added to the catchment tank; the disadvantage of this approach is that the stock solution tanks must be topped up regularly.

Experiments at the Glasshouse Crops Research Institute (GCRI) in Littlehampton, England, have shown that plants grown with the NFT technique can tolerate a wide range of nutrient concentrations. For example, in one study on tomatoes they found no significant loss of yield when the nitrogen (as NO_3^-) concentration was reduced from 320 to 10 ppm, provided that the concentrations were effectively maintained. In commercial practice, however, an average nutrient concentration is preferred because it ensures an adequate reserve of nutrients within the system.

Some general recommendations, based on commercial experience and on research carried out at GCRI, are available on the optimum concentration of nutrients in the NFT solution; they are summarized in Table 27.

On the basis of the nutrient content of the water supply, two major recommendations are available regarding the composition of the NFT fertilizer and acid-concentrated stock solutions. The fertilizer concentrations given in Table 28 apply to areas with a moderately hard water supply, with alkalinity in excess of 100 ppm calcium carbonate equivalent.

Where routine analysis of the nutrient solution shows that calcium has accumulated in the solution, it might be necessary to reduce the amount of calcium nitrate in stock solution A. For each kilogram of calcium nitrate omitted from solution A, increase the potassium nitrate by 0.86 kg, to compensate for the NO_3^- lost in the reduction of calcium nitrate; and decrease the potassium sulfate by 0.74 kg, to counterbalance the increase in potassium from the added potassium nitrate. The water supply could contain enough calcium, i.e., more than 120 ppm, to preclude adding calcium nitrate.

Table 27 Target nutrient levels in NFT solution

Element	Minimum[a] (pH 5.5, EC 1800 µS cm^{-1})	Optimum (pH 6.0, EC 2000–2500 µS cm^{-1})	Maximum (pH 6.5, EC 3500 µS cm^{-1})
Nitrogen (NO_3)	50	150–200	300
Nitrogen (NH_4)	5	10–15	20
Phosphorus	20	50	200
Potassium	100	300–500	800
Calcium	125	150–300	400
Magnesium	25	50	100
Iron	1.5	6	12
Manganese	0.5	1	2.5
Copper	0.05	0.1	1
Zinc	0.05	0.5	2.5
Boron	0.1	0.3–0.5	1.5
Molybdenum	0.01	0.05	0.1
Sodium	†	†	250
Chloride	†	†	400
Sulfur	–	50–200	–

[a] Regard concentrations listed as minimum as the approximate lower limit of a preferred range; in general, these minimum values are above those at which symptoms of deficiency develop.

† As little as possible.

However, in areas where the water supply has an alkalinity of less than 100 ppm calcium carbonate equivalent, increase the calcium nitrate in stock solution A. The fertilizer formula then takes a new form, as shown in Table 29.

The grouping of fertilizers and acids in Tables 28 and 29 can be altered to include some or all of the potassium nitrate in stock solution A, which may be desirable when using little calcium nitrate. Also, when you know the acid requirement from previous experience, include a portion of it (but only as nitric) in stock solutions A and B. This practice has the dual benefit of preventing precipitates in stocks A and B and allowing the nitrogen content of the nitric acid to be taken into account when formulating stock solutions. In fact, fertilizers can be grouped into stock solutions in a variety of ways, the only limitation being that calcium be kept apart from phosphate and sulfate.

The formulas in Tables 28 and 29 are good examples of how to vary the composition of the nutrient concentrates for particular purposes. Beginners who cannot or do not wish to prepare their own stock solutions can buy various commercial nutrient formulations. These products, because they are made for universal application, may not prove the ideal choice for every crop, but they have given good general results. However, commercial growers with a significant part of their cucumber crop in NFT should make every effort to obtain basic fertilizers and mix them to provide the plants with the best nutrient mix according to the latest research findings. Table 30 constitutes the latest fertilizer feeding recommendations for NFT cucumber cropping at the time of writing.

Table 28 Fertilizer formulation for NFT used with hard water[a]

Stock A (1000 L total volume)		Stock B (1000 L total volume)		Stock C (1000 L total volume)	
Chemical	Amount	Chemical	Amount	Chemical	Amount
Calcium nitrate	50 kg	Potassium nitrate	80 kg	Nitric acid (67%)	54 L
		Potassium sulfate	40 kg	Phosphoric acid (85%)	24 L
		Magnesium sulfate	60 kg		
		Ammonium nitrate	0.6 kg		
		Iron chelate (15% Fe)	3.0 kg		
		Manganese sulfate (25% Mn)	0.4 kg		
		Boric acid (14% B)	0.24 kg		
		Copper sulfate (25% Cu)	80 g		
		Zinc sulfate (23% Zn)	40 g		
		Ammonium molybdate (57% Mo)	10 g		

[a] No phosphatic fertilizer has been included other than the phosphoric acid in stock solution C. Where the water is not particularly hard and the acid requirement is correspondingly low, include 1.5 kg of monopotassium phosphate in stock solution B while decreasing the amount of potassium sulfate from 4.0 to 3.0 kg.

Note: Assuming a dilution ratio of 1:100 for stock solutions A and B, the theoretical nutrient concentrations in the circulating diluted NFT solution are as follows:

Nutrient	(ppm)
Nitrogen*	192
Phosphorus†	–
Potassium	490
Magnesium	59
Calcium‡	85
Iron	4.5
Manganese	1
Boron	0.34
Copper	0.20
Zinc	0.09
Molybdenum	0.05

* The nitric acid of stock solution C supplies additional nitrogen.
† The phosphoric acid of stock solution C supplies some phosphorus.
‡ The calcium content of the water supply has not been taken into account.

Table 29 Fertilizer formulation for use with NFT in soft water areas

Stock A (1000 L total volume)		Stock B[a] (1000 L total volume)		Stock C (1000 L total volume)	
Chemical	Amount	Chemical	Amount	Chemical	Amount
Calcium nitrate	75 kg	Potassium nitrate	90.0 kg	Nitric acid (85%)	89 L
		Monopotassium phosphate	30.0 kg		
		Magnesium sulfate	60.0 kg		
		Iron chelate (15% Fe)	3.0 kg		
		Manganese sulfate (25% Mn)	0.4 kg		
		Boric acid (14% B)	0.24 kg		
		Copper sulfate (25% Cu)	80 g		
		Zinc sulfate (23% Zn)	40 g		
		Ammonium molybdate (57% Mo)	10 g		

[a] It may be necessary to slightly acidify stock solution B with a small amount of nitric acid (20 mL) to prevent salt precipitation, e.g., magnesium phosphate.

Note: Assuming a dilution ratio of 1:100 for stock solutions A and B, the theoretical nutrient concentrations in the circulating diluted NFT solution are as follows:

Nutrient	(ppm)
Nitrogen*	214
Phosphorus	68
Potassium	434
Magnesium	59
Calcium†	128
Iron	4.5
Manganese	1.0
Boron	0.34
Copper	0.20
Zinc	0.09
Molybdenum	0.05

* The nitric acid of stock solution C supplies additional nitrogen; however, the amount is small because the amount of acid needed to control the pH of soft water is far less than that required for hard water.

† The calcium content of the water supply has not been taken into account.

Table 30 Recommended nutrient levels for cucumbers in NFT solution

Stock solution A (1000 L total volume)		Stock solution B (1000 L total volume)	
Chemical	Amount	Chemical	Amount
Calcium nitrate	44.4 kg	Monopotassium phosphate	22.0 kg
Potassium nitrate	62.7 kg	Magnesium sulfate	50.0 kg
Ammonium nitrate	5.0 kg	Iron chelate (13% iron)[a]	1.0 kg
		Manganese sulfate (25% Mn)[a]	250.0 g
		Boric acid (14% B)[a]	90.0 g
		Copper sulfate (25% Cu)[a]	30.0 g
		Zinc sulfate (23% Zn)[a]	35.0 g
		Ammonium molybdate (57% Mo)[a]	8.0 g

Notes:

- Prepare the final solution by adding equal volumes of both stock solutions in water until a recommended final solution EC of 2200 μS cm^{-1} is achieved; adjust the pH to 6.2 by adding phosphoric (low-light conditions) or nitric (high-light conditions) acid. Ideally, stock solutions are mixed and pH is adjusted automatically by electrical conductivity and pH controllers.
- When starting a new crop, begin with an EC of 1500 μS cm^{-1} and gradually increase to 2200 μS cm^{-1} over 1 week.
- A background EC of 300–600 μS cm^{-1} from the water supply is assumed.

Nutrient	(ppm)
Nitrate (NO_3–N)	156
Ammonium (NH_4–N)	12
Phosphorus	50
Potassium	302
Calcium	84
Magnesium	50
Iron	1.3
Manganese	0.62
Boron	0.12
Copper	0.07
Zinc	0.08
Molybdenum	0.03

[a] Alternatively, include 2.0 kg of Plant Product Chelated Micronutrient mix; which provides the following micronutrient concentrations: 1.4 ppm Fe, 0.4 ppm Mn, 0.08 ppm Zn, 0.26 ppm B, 0.02 ppm Cu, and 0.012 ppm Mo.

Warning:

The NFT system is **not recommended for the long-term cucumber crop** because of frequent and unresolved occurrences of crop losses from widespread root death; consult your local horticultural crop adviser before commiting a cucumber crop to NFT (Plate IV*f*).

CONVERSION FACTORS

Multiply an imperial number by the conversion factor given to get its metric equivalent.

Divide a metric number by the conversion factor given to get its equivalent in imperial units.

Imperial units	Approximate conversion factor	Metric units	
Length			
inch	25	millimetre	(mm)
foot	30	centimetre	(cm)
yard	0.9	metre	(m)
mile	1.6	kilometre	(km)
Area			
square inch	6.5	square centimetre	(cm^2)
square foot	0.09	square metre	(m^2)
square yard	0.836	square metre	(m^2)
square mile	259	hectare	(ha)
acre	0.40	hectare	(ha)
Volume			
cubic inch	16	cubic centimetre	(cm^3, mL, cc)
cubic foot	28	cubic decimetre	(dm^3)
cubic yard	0.8	cubic metre	(m^3)
fluid ounce	28	millilitre	(mL)
pint	0.57	litre	(L)
quart	1.1	litre	(L)
gallon (Imp.)	4.5	litre	(L)
gallon (U.S.)	3.8	litre	(L)
Weight			
ounce	28	gram	(g)
pound	0.45	kilogram	(kg)
short ton (2000 lb)	0.9	tonne	(t)
Pressure			
pounds per square inch	6.9	kilopascal	(kPa)
Power			
horsepower	746	watt	(W)
	0.75	kilowatt	(kW)
Speed			
feet per second	0.30	metres per second	(m/s)
miles per hour	1.6	kilometres per hour	(km/h)
Agriculture			
gallons per acre	11.23	litres per hectare	(L/ha)
quarts per acre	2.8	litres per hectare	(L/ha)
pints per acre	1.4	litres per hectare	(L/ha)
fluid ounces per acre	70	milliltres per hectare	(mL/ha)
tons per acre	2.24	tonnes per hectare	(t/ha)
pounds per acre	1.12	kilograms per hectare	(kg/ha)
ounces per acre	70	grams per hectare	(g/ha)
plants per acre	2.47	plants per hectare	
Temperature			
degrees Fahrenheit	(°F − 32) x 0.56 = °C or °F = 1.8 (°C) + 32	degrees Celsius	(°C)

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